N95- 23626

34
4/3415
p. 33

CFD PARAMETRIC STUDY OF CONSORTIUM IMPELLER

Gary C. Cheng*, Y.S. Chen†, R. Garcia‡, and R.W. Williams§

Abstract

Current design of high performance turbopumps for rocket engines requires effective and robust analytical tools to provide design impact in a productive manner. The main goal of this study is to develop a robust and effective computational fluid dynamics (CFD) pump model for general turbopump design and analysis applications. A Finite Difference Navier-Stokes flow solver, FDNS, which includes the extended k-ε turbulence model and appropriate moving interface boundary conditions, was developed to analyze turbulent flows in turbomachinery devices. A second-order central difference scheme plus adaptive dissipation terms was employed in the FDNS code, along with a predictor plus multi-corrector pressure-based solution procedure. The multi-zone, multi-block capability allows the FDNS code to efficiently solve flow fields with complicated geometry. The FDNS code has been benchmarked by analyzing the pump consortium inducer, and it provided satisfactory results. In the present study, a CFD parametric study of the pump consortium impeller was conducted using the FDNS code. The pump consortium impeller, with partial blades, is a new design concept of the advanced rocket engines. The parametric study was to analyze the baseline design of the consortium impeller and its modification which utilizes TANDEM blades. In the present study, the TANDEM blade configuration of the consortium impeller considers cut full blades for about one quarter chord length from the leading edge and clocks the leading edge portion with an angle of 7.5 or 22.5 degrees. The purpose of the present study is to investigate the effect and trend of the TANDEM blade modification and provide the result as a design guideline. A 3-D flow analysis, with a 103 x 23 x 30 mesh grid system and with the inlet flow conditions measured by Rocketdyne, was performed for the baseline consortium impeller. The numerical result shows that the mass flow rate splits through various blade passages are relatively uniform. Due to the complexity of blade geometries, the TANDEM blade configurations were analyzed with the multi-zone grid structure. Both the 7.5°- and the 22.5°-clocking TANDEM blade cases utilized a 80K mesh system. The numerical result of two TANDEM blade modifications indicates the efficiency and the head are worse than those of the baseline case due to larger flow distortion. The gap between the TANDEM blade and the full blade allows the flow passes through and heavily loads the pressure side of the partial blade such that flow reversal occurs near the suction side of the splitter. The flow split at the exit of impeller blades is very non-uniform for TANDEM blade cases, and this will greatly induce the side load on the diffuser. Therefore, the TANDEM blade modification in the present CFD analysis does not improve the performance of the consortium impeller.

---

* SECA, Inc., 3313 Bob Wallace Ave., Suite 202, Huntsville, AL

† Engineering Sciences, Inc., 4920 Corporate Dr., Suite K, Huntsville, AL

‡ ED 32, NASA/Marshall Space Flight Center, Huntsville, AL

§ ED 32, NASA/Marshall Space Flight Center, Huntsville, AL

CFD PARAMETRIC STUDY OF CONSORTIUM IMPELLER

-- 100% DESIGN FLOW CASE --

Gary C. Cheng, SECA, Inc.

Y.S. Chen, ESI

R. Garcia and R.W. Williams
NASA Marshall Space Flight Center

NASA Contract No. NAS8-38868

ELEVENTH WORKSHOP FOR CFD APPLICATIONS IN ROCKET PROPULSION
NASA/MSFC, APRIL 20-22, 1993

OBJECTIVE

- DEVELOP A ROBUST AND EFFECTIVE CFD PUMP MODEL FOR THE DESIGN AND ANALYSIS OF TURBOPUMP COMPONENTS
- BENCHMARK THE PUMP MODEL AND COMPUTE THE CONSORTIUM IMPELLER WITH THE BASELINE GEOMETRY AT 100% DESIGN FLOW RATE
- STUDY THE EFFECT OF TANDEM BLADE MODIFICATIONS ON THE CONSORTIUM IMPELLER PERFORMANCE

TEST CONFIGURATION SETUP

- **BASELINE IMPELLER**
  - ONE ZONE, 103 x 23 x 30 GRIDS
  - I: STREAMWISE DIRECTION
  - J: HUB-TO-TIP DIRECTION
  - K: BLADE-TO-BLADE DIRECTION (SUCTION TO PRESSURE)

- **TANDEM BLADE WITH 7.5° CLOCKING**
  - FOUR ZONES: Zone #1, 15 x 33 x 23; Zone #2, 51 x 7 x 23; Zone #3, 51 x 17 x 23; Zone #4, 51 x 11 x 23; Zone #5, 31 x 33 x 23
  - I: STREAMWISE DIRECTION

- J: BLADE-TO-BLADE DIRECTION (PRESSURE TO SUCTION)
- K: HUB-TO-TIP DIRECTION

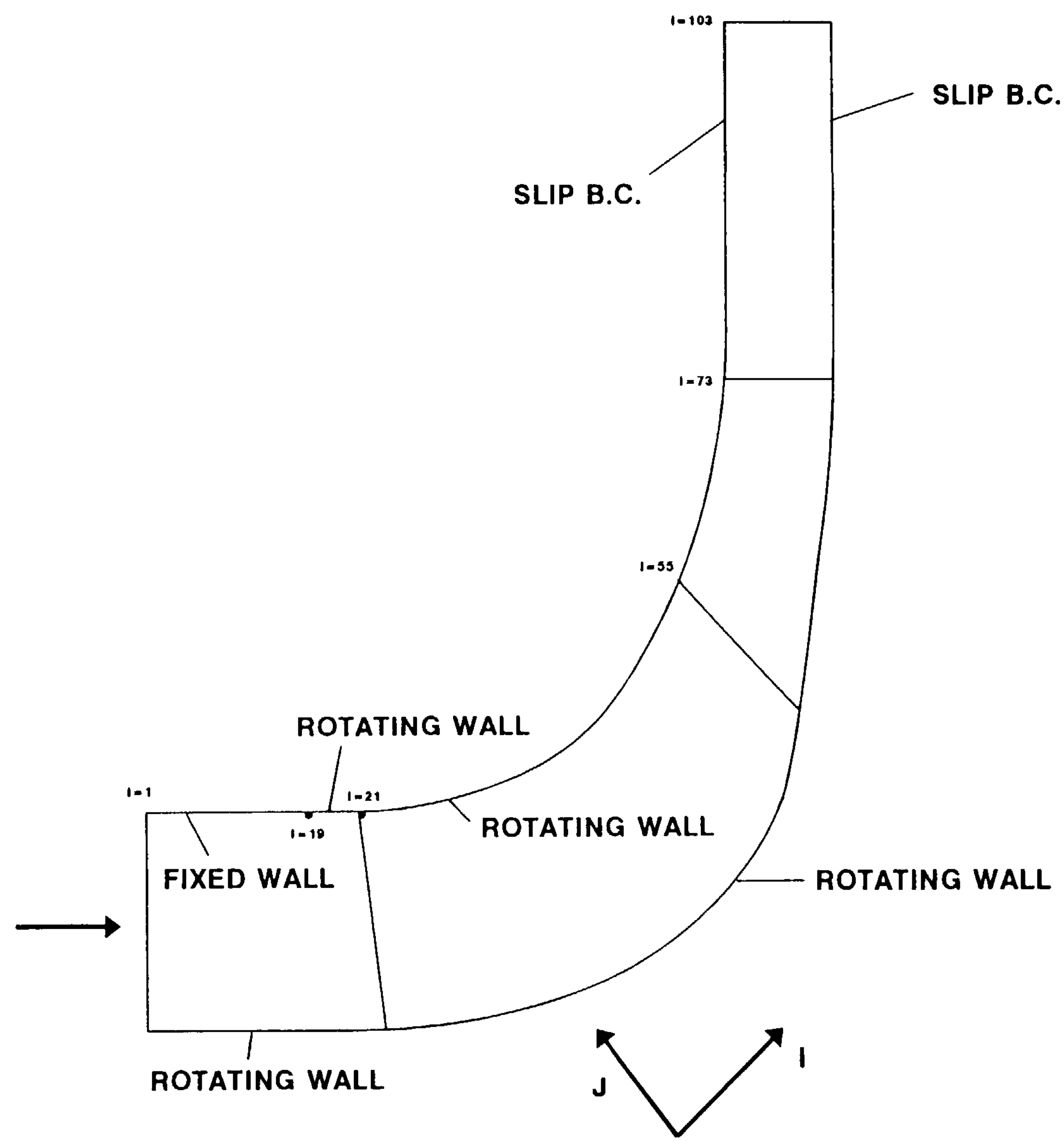
TANDEM BLADE WITH 22.5° CLOCKING

- FOUR ZONES: Zone #1, 15 x 33 x 23; Zone #2, 51 x 13 x 23; Zone #3, 51 x 17 x 23; Zone #4, 51 x 5 x 23; Zone #5, 31 x 33 x 23

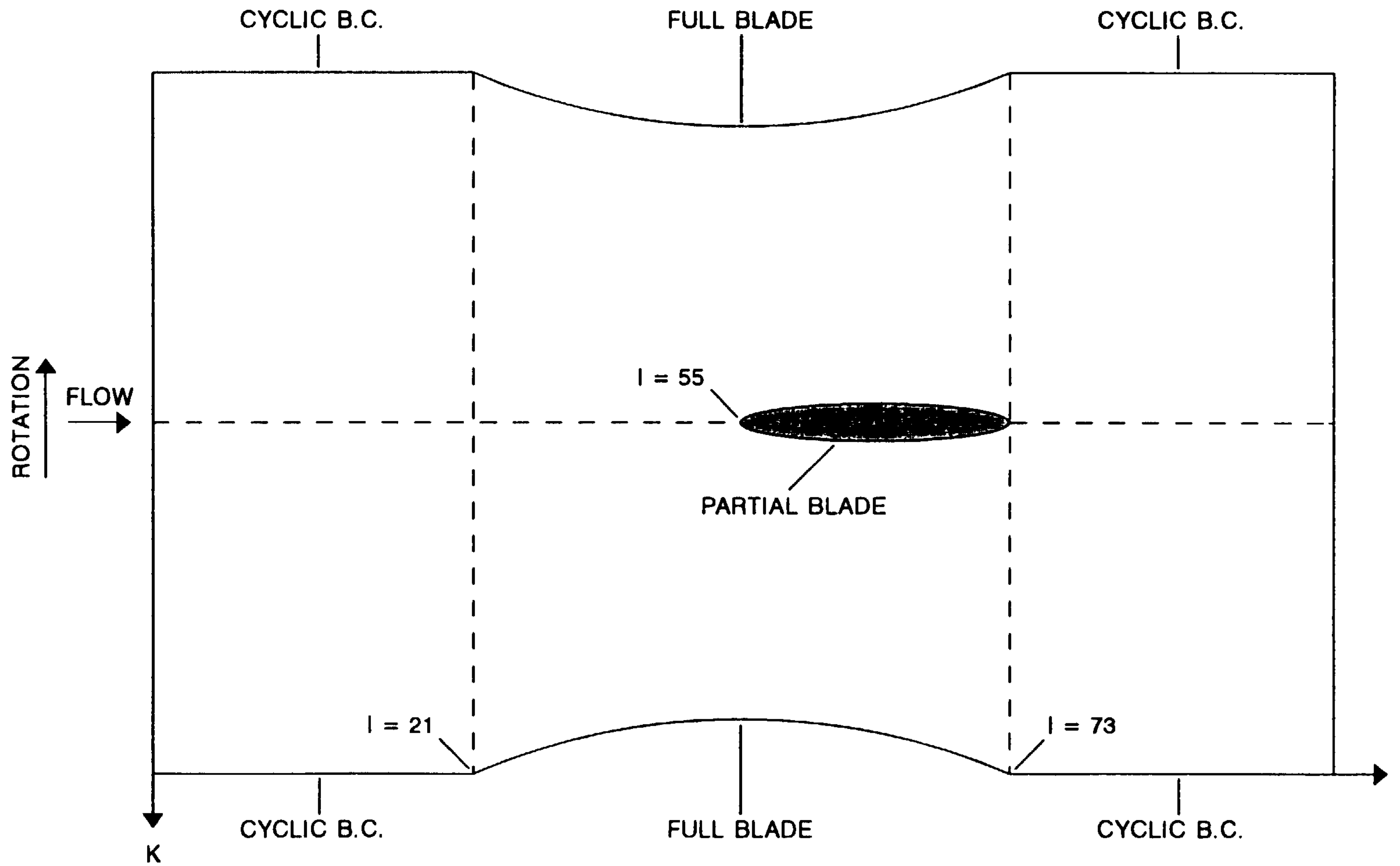
- I: STREAMWISE DIRECTION
- J: BLADE-TO-BLADE DIRECTION (PRESSURE TO SUCTION)
- K: HUB-TO-TIP DIRECTION

NUMERICAL METHOD

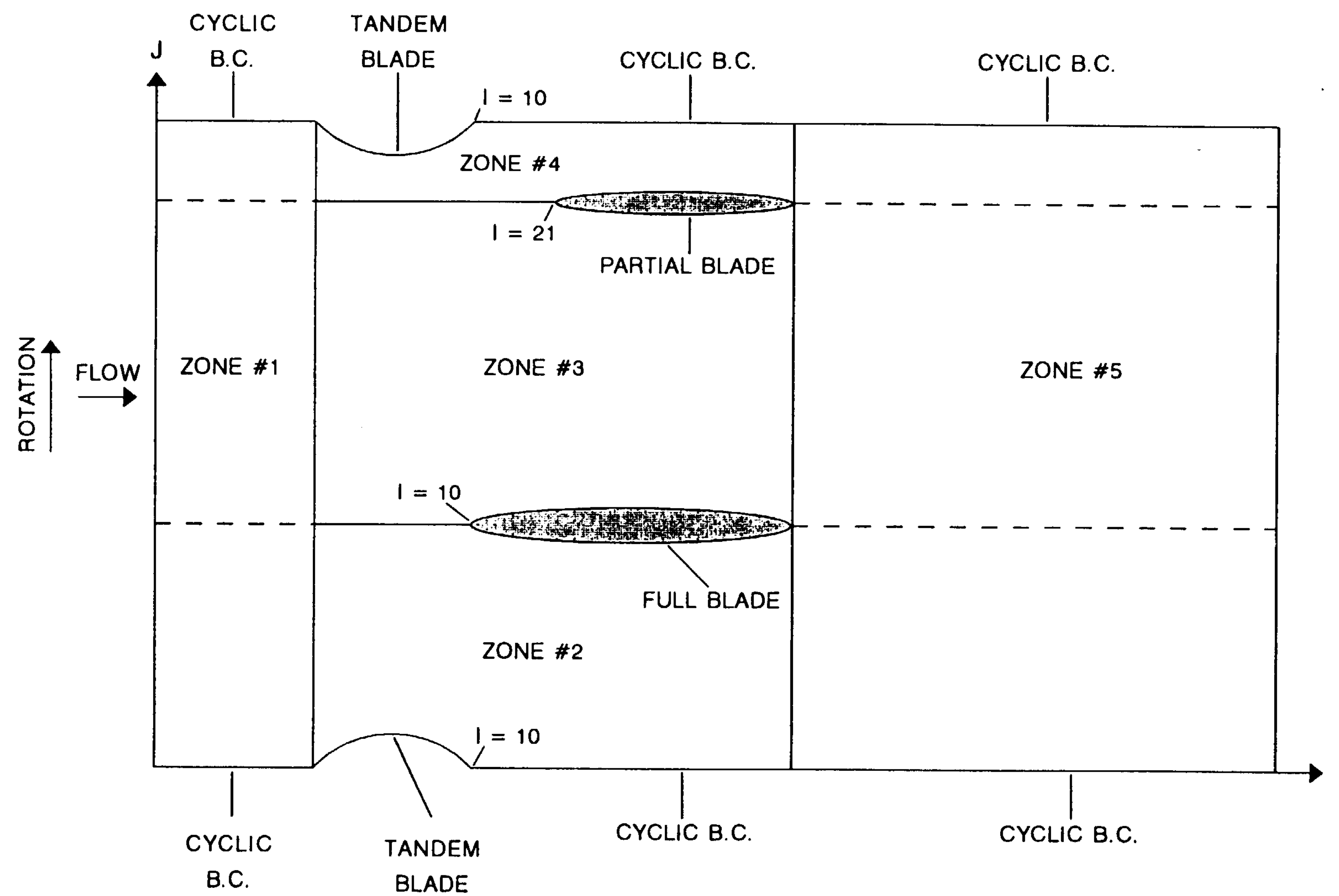
- NAVIER-STOKES FLOW SOLVER: **FDNS** CODE
- PRESSURE BASED FINITE DIFFERENCE APPROACH
- PREDICTOR PLUS MULTI-CORRECTOR TIME MARCHING SCHEME
- MULTI-ZONE, BODY-FITTED COORDINATE SYSTEM
- SECOND-ORDER CENTRAL PLUS DISSIPATION SCHEME FOR CONVECTION TERMS
- MULTI-BLOCK, IMPLICIT POINT-BY-POINT SOLVER
- STANDARD AND EXTENDED K-ε TURBULENCE MODELS



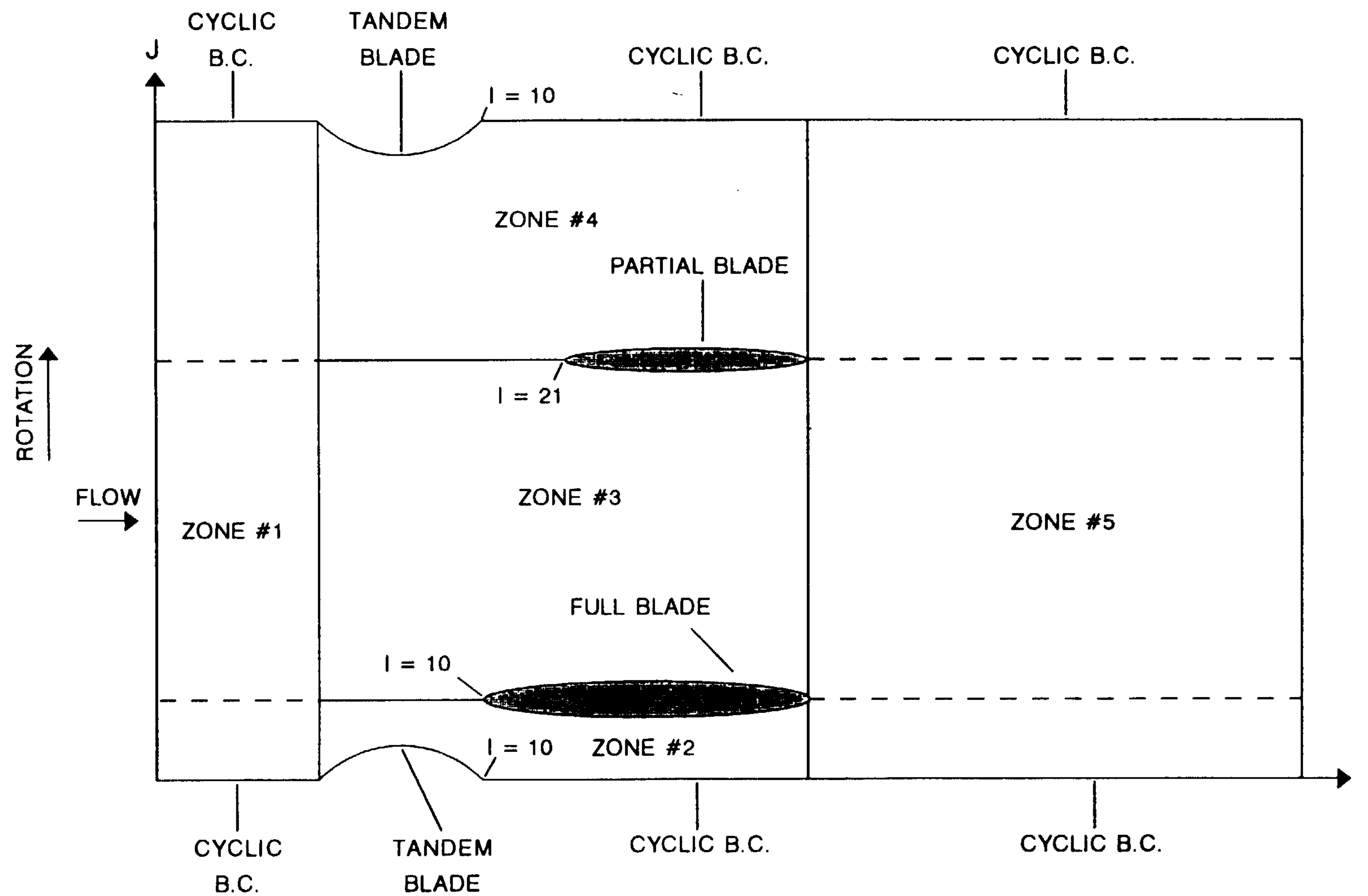
The Mesh System Layout for the Consortium Impeller (Hub-to-Tip)



The Mesh System Layout for the Baseline Consortium Impeller



The Mesh System Layout for 22.5° Clocking TANDEM Blade Impeller



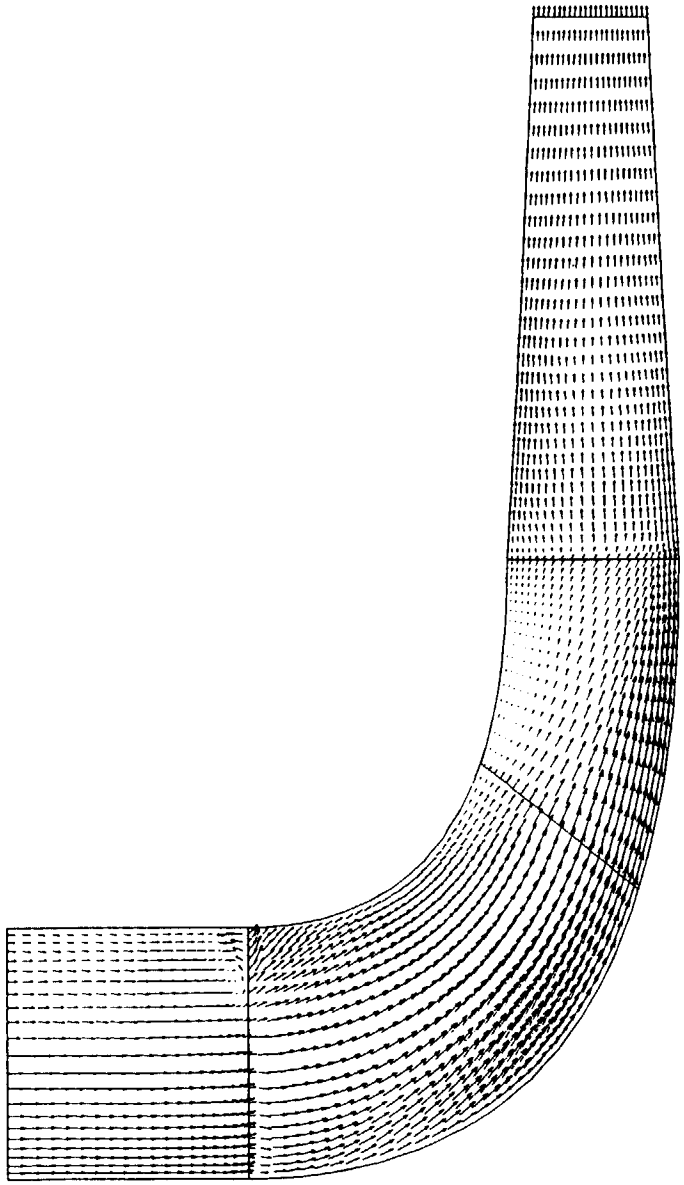
The Mesh System Layout for 7.5° Clocking TANDEM Blade Impeller

- **TEST CONDITIONS**

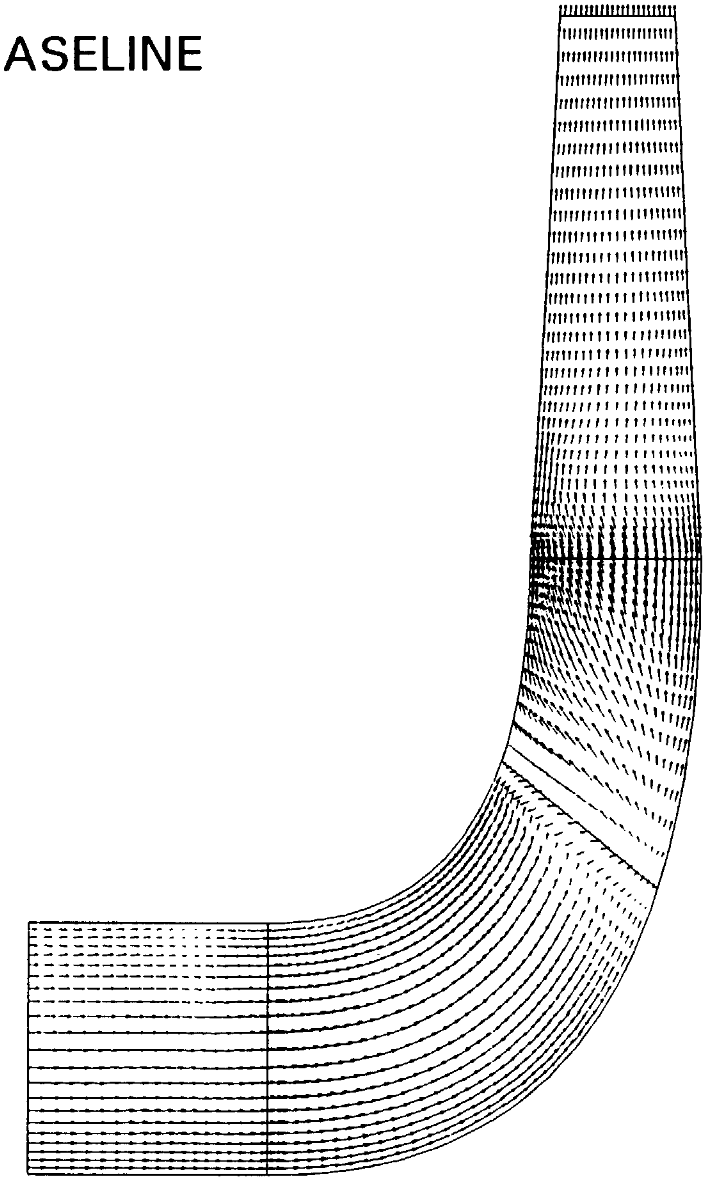
Full Blades/Partial Blades	6/6
Working Medium	Water (70 °F)
Shaft Speed	6322 rpm
Exit Tip Diameter	9.045 inches
Inlet Hub Diameter	3.9 inches
Inlet Tip Diameter	6.0 inches
Reference Velocity	23.41 ft/sec
Reference Reynolds Number	1.59×10^7 ft^{-1}
Mass Flow Rate	160.8 lb/sec

- MEASURED AXIAL AND TANGENTIAL VELOCITY PROFILES DOWNSTREAM OF THE INDUCER EXIT ARE USED AS INLET CONDITIONS TO THE IMPELLER

BASELINE

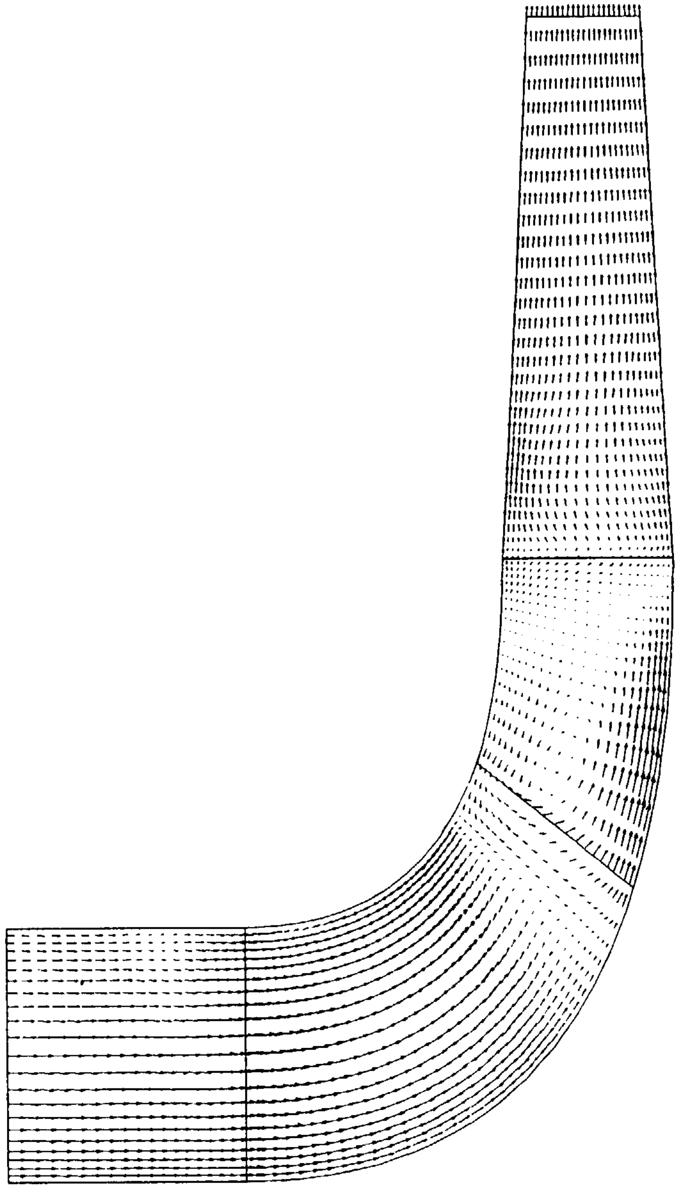


Suction Side of Full Blade

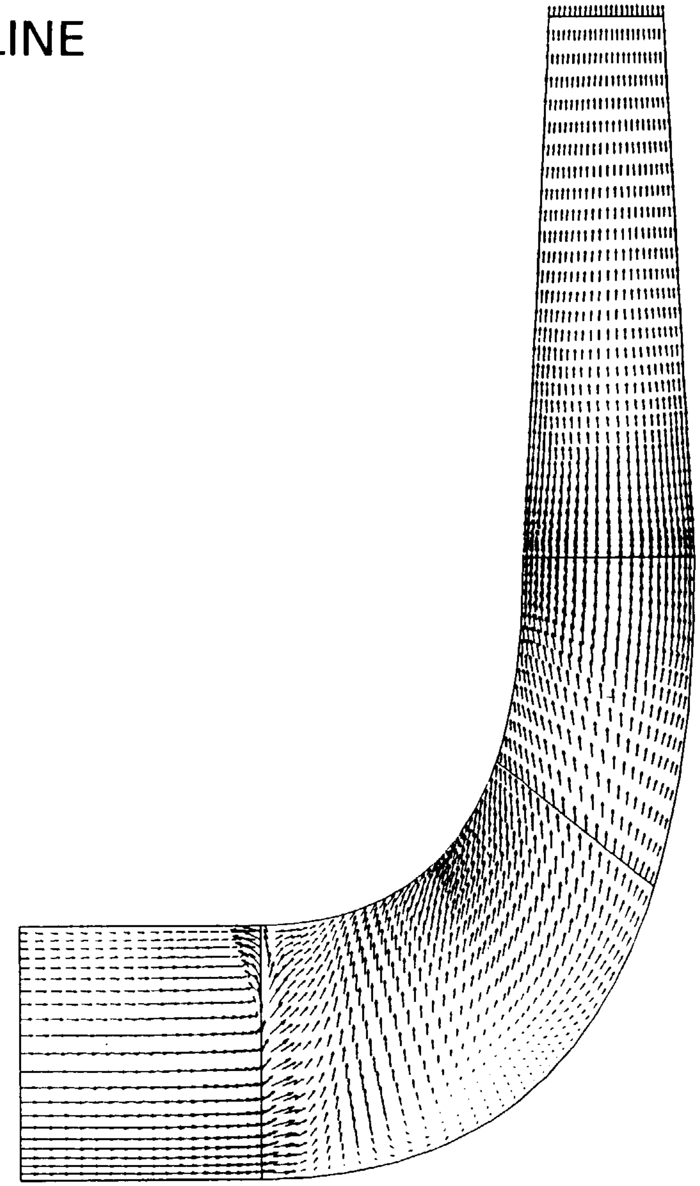


Pressure Side of Partial Blade

BASELINE

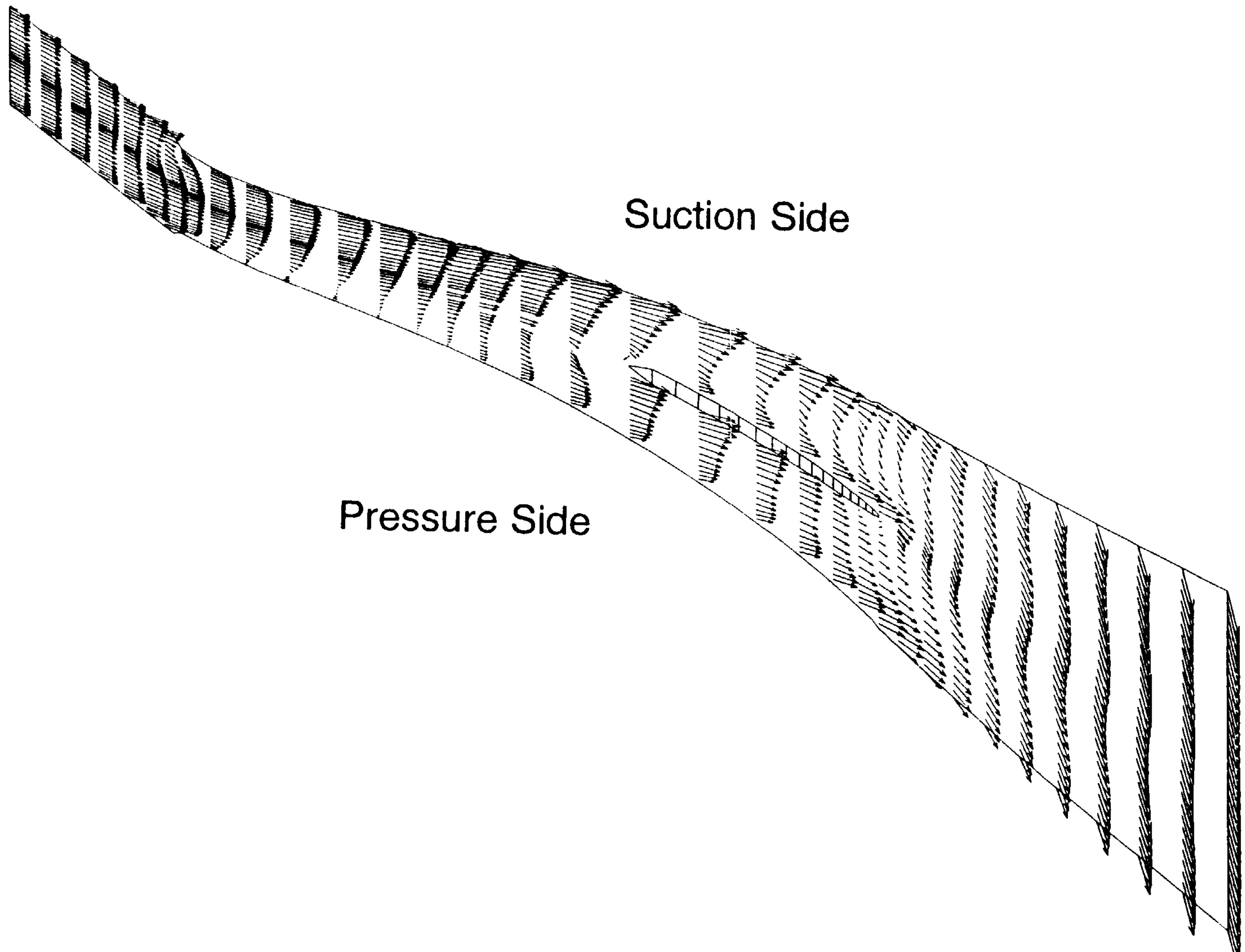


Suction Side of Partial Blade



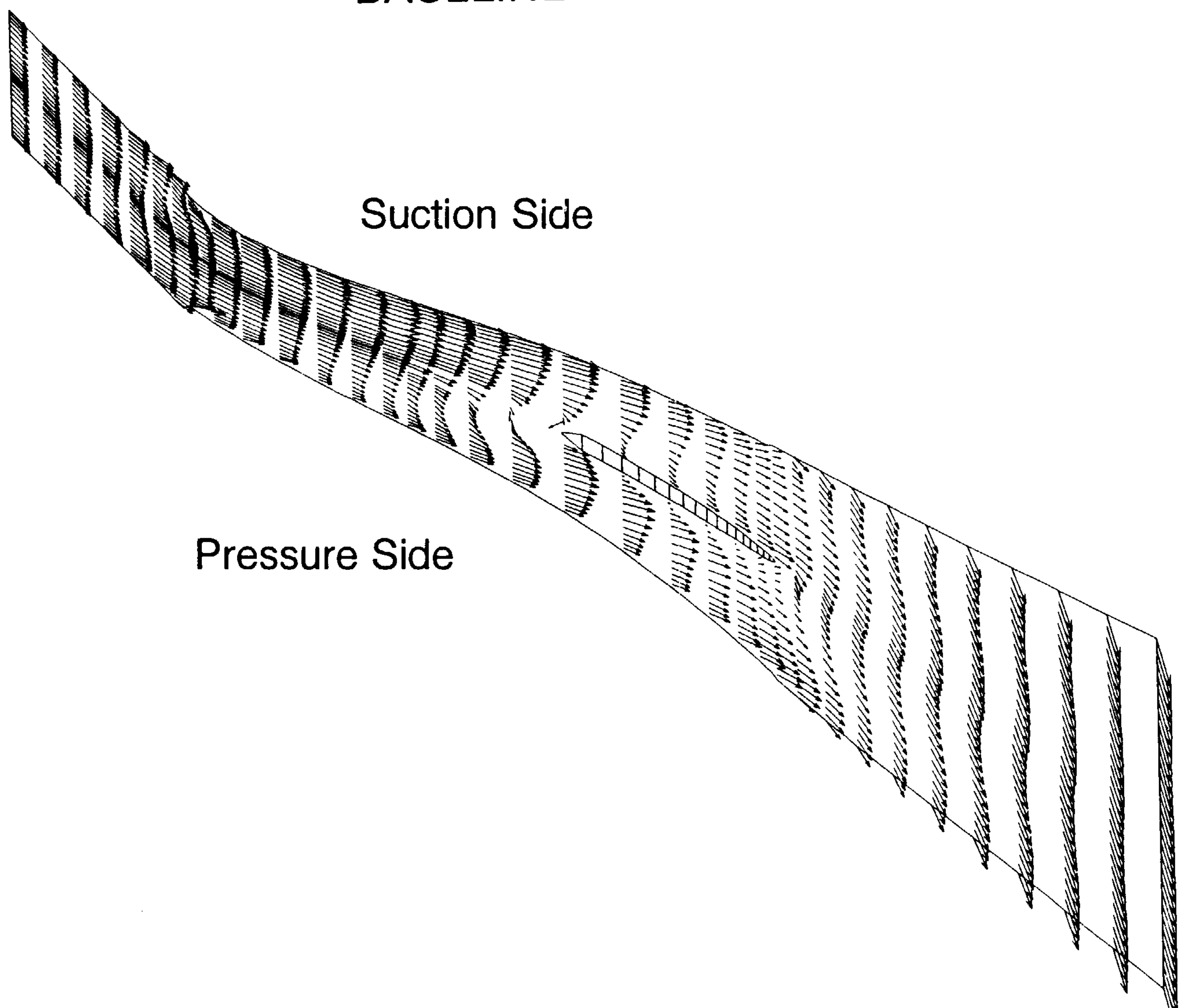
Pressure Side of Full Blade

BASELINE



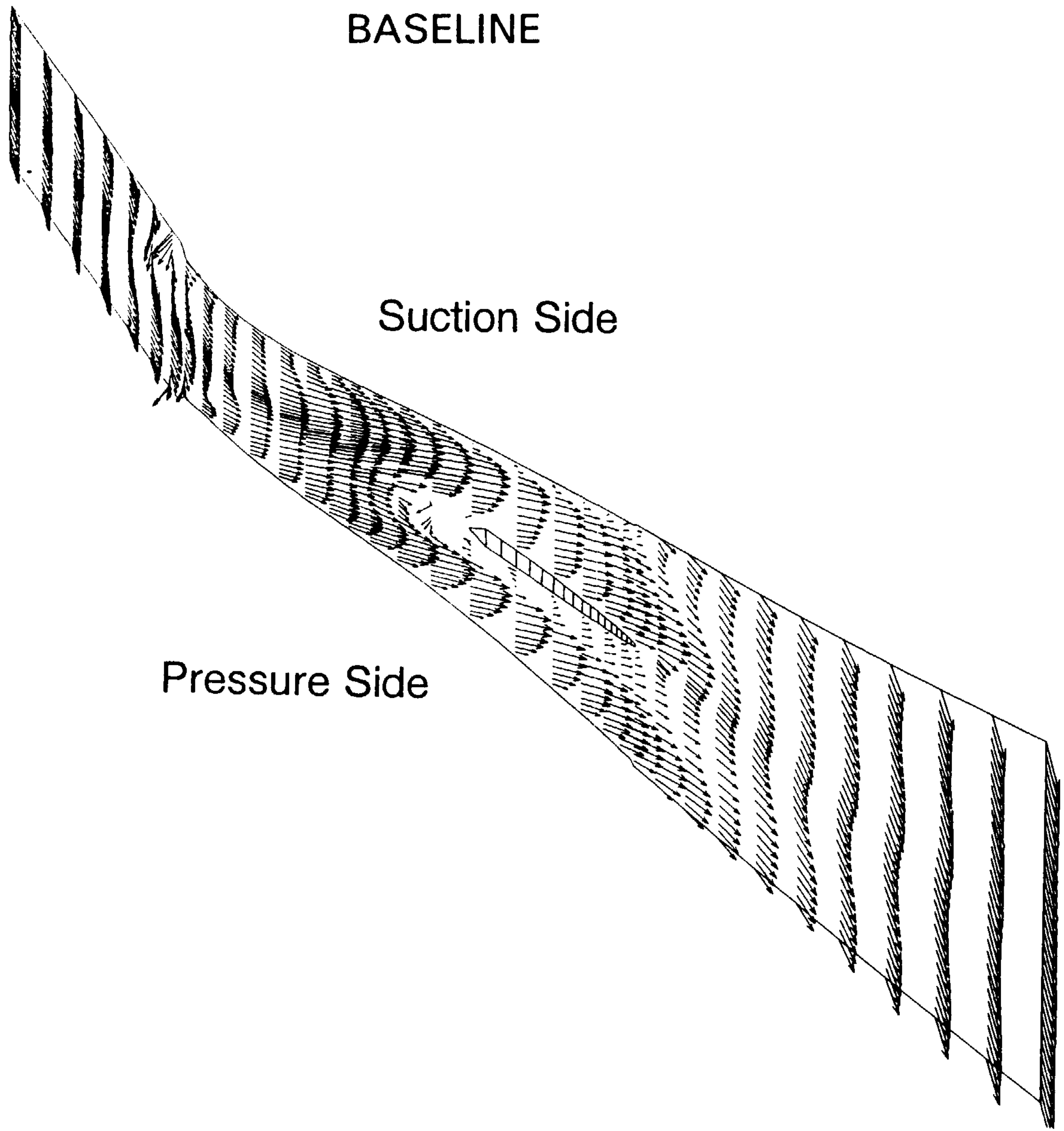
Velocity Vectors Near the Hub

BASELINE



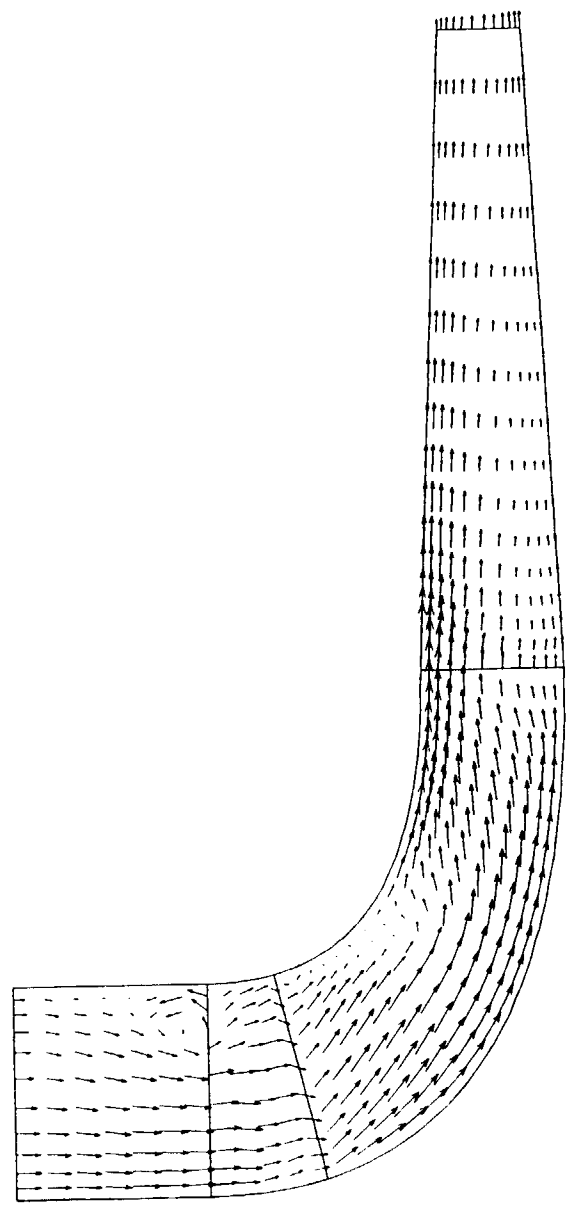
Velocity Vectors at the Mid Span

BASELINE

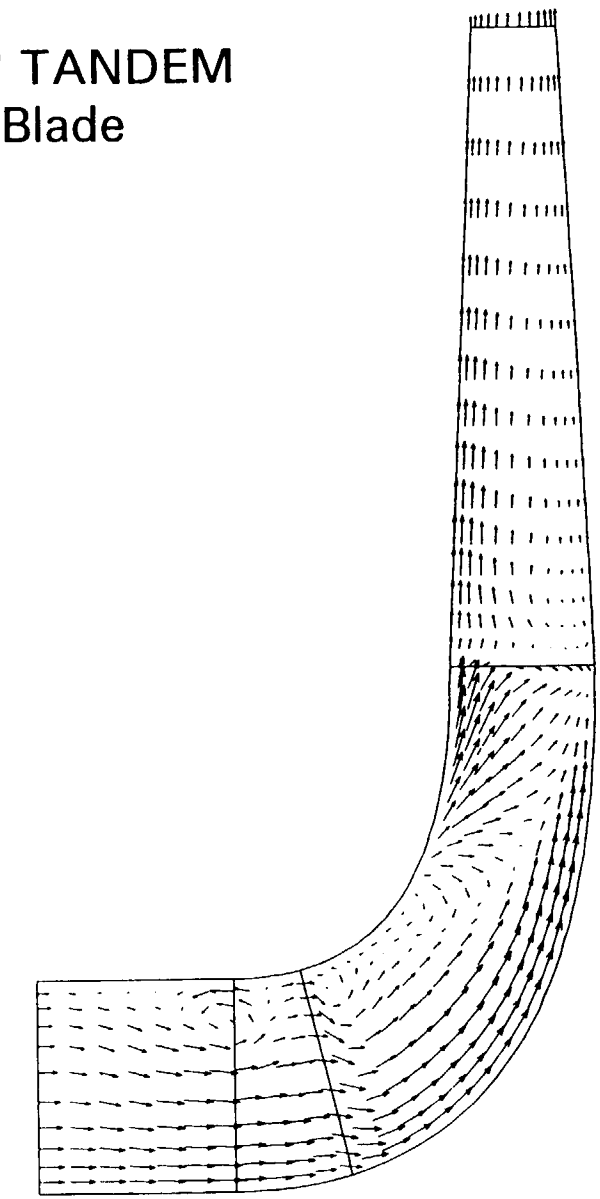


Velocity Vectors Near the Shroud

7.5° TANDEM
Blade

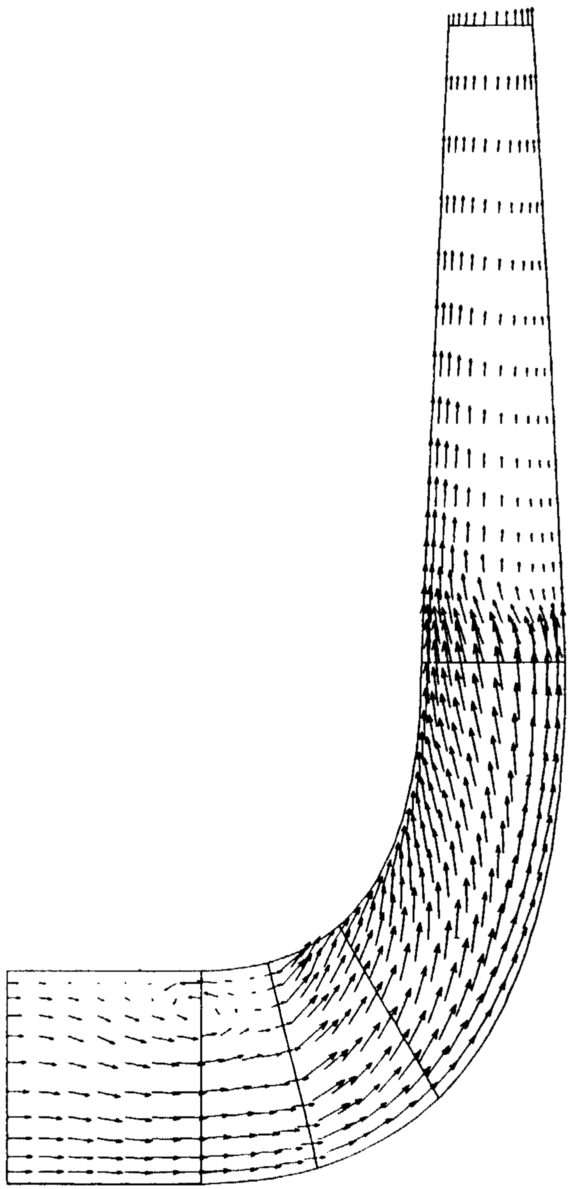


Pressure Side of Tandem Blade

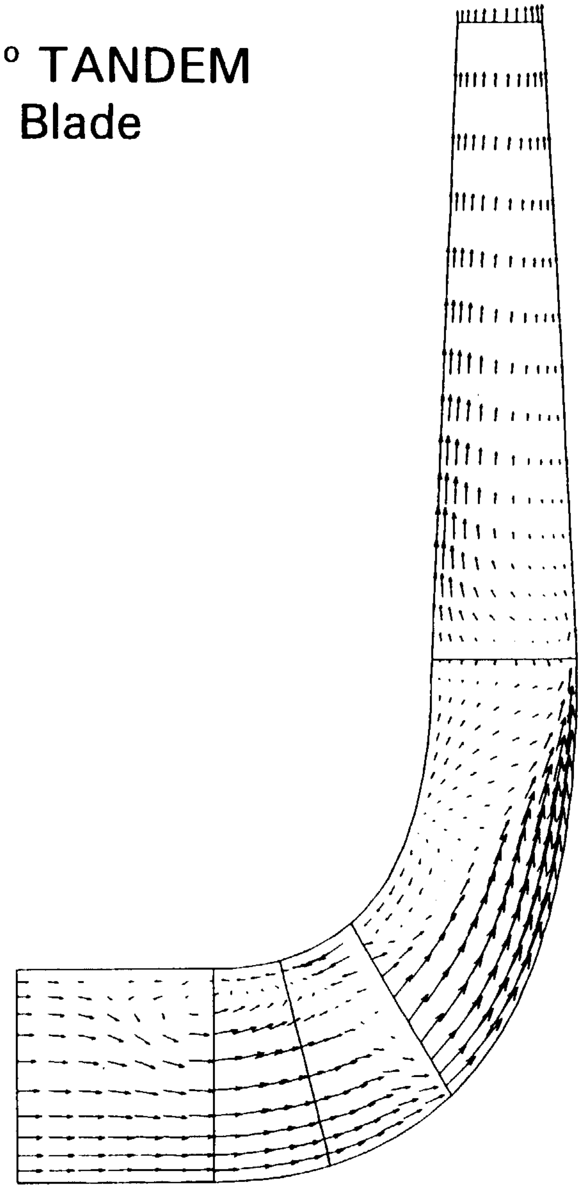


Suction Side of Full Blade

7.5° TANDEM
Blade

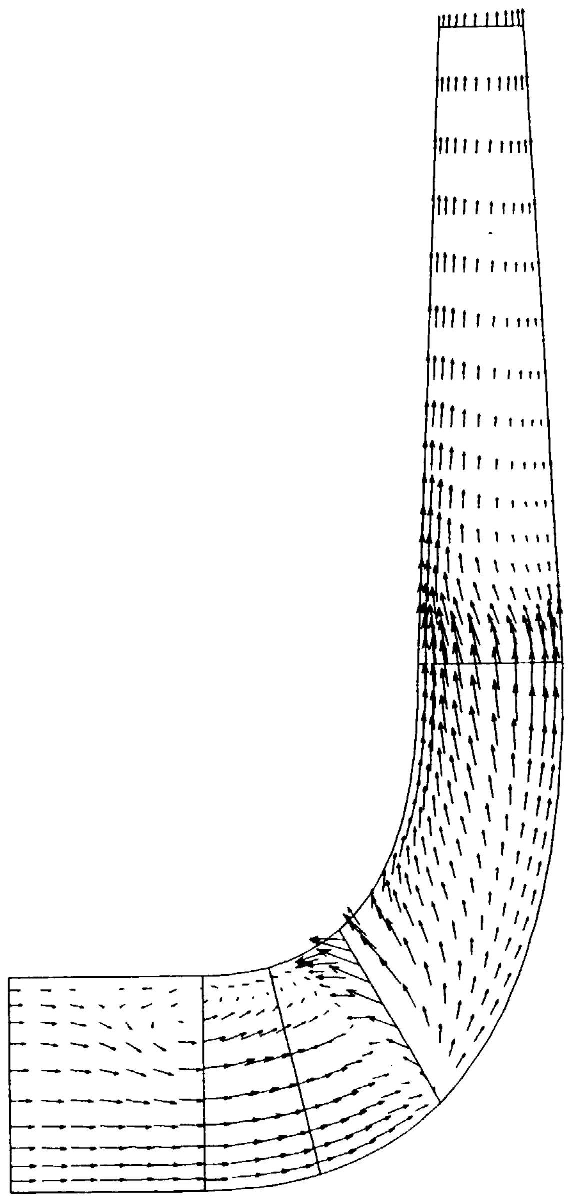


Pressure Side of Full Blade

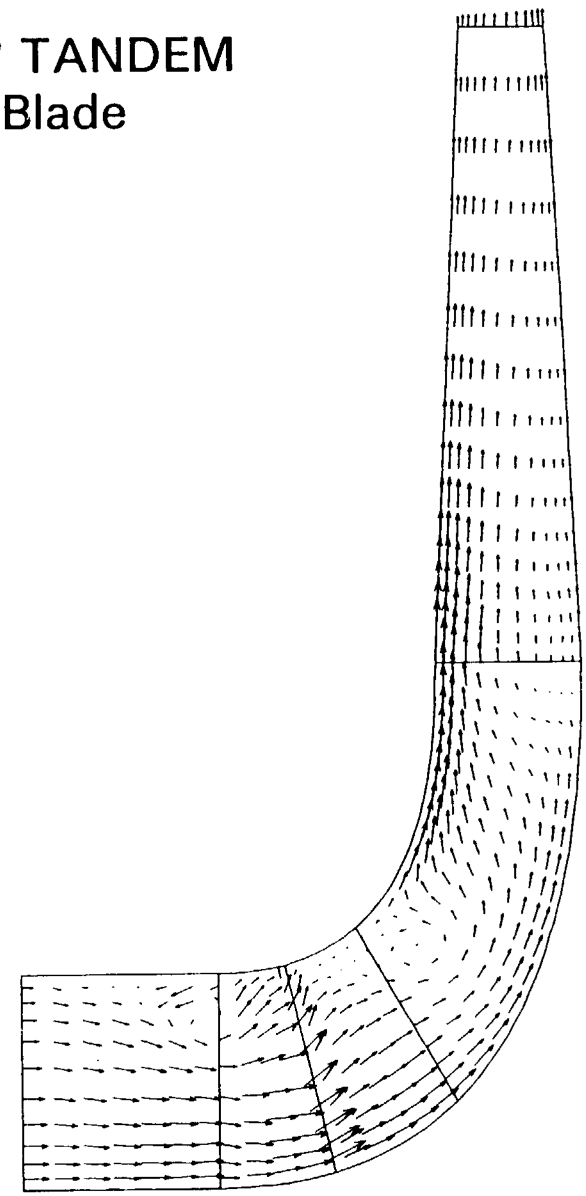


Suction Side of Partial Blade

7.5° TANDEM
Blade

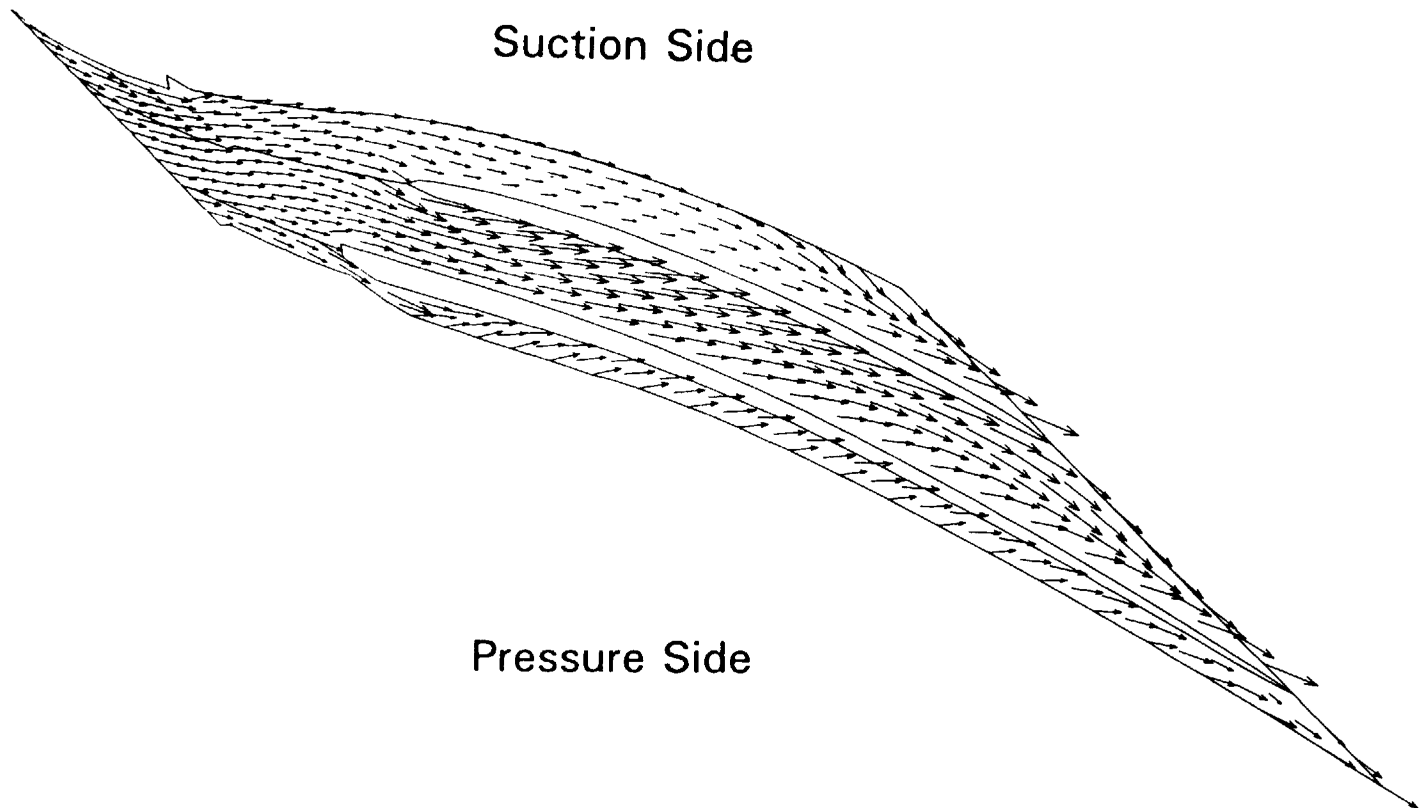


Pressure Side of Partial Blade



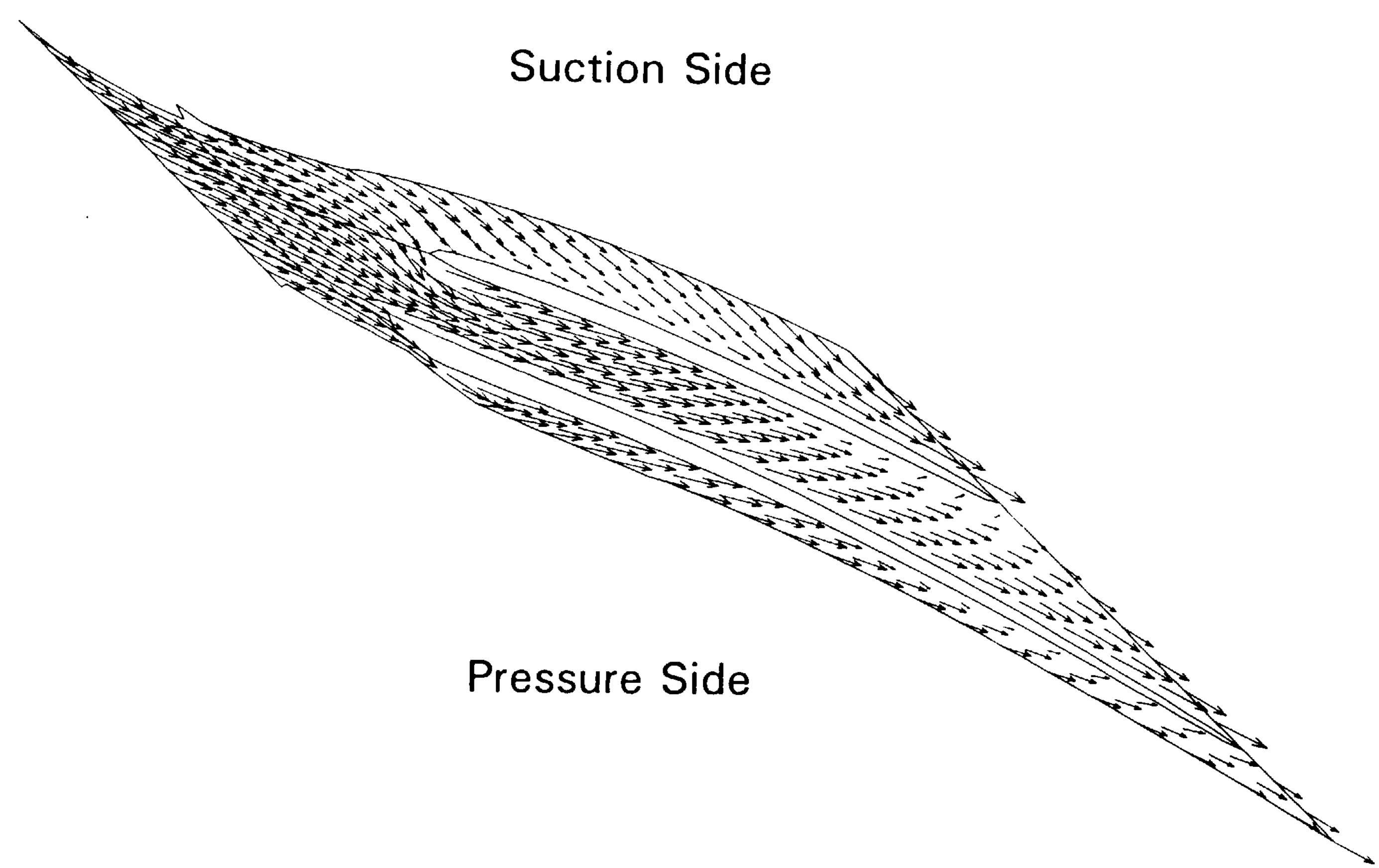
Suction Side of TANDEM Blade

7.5° TANDEM Blade



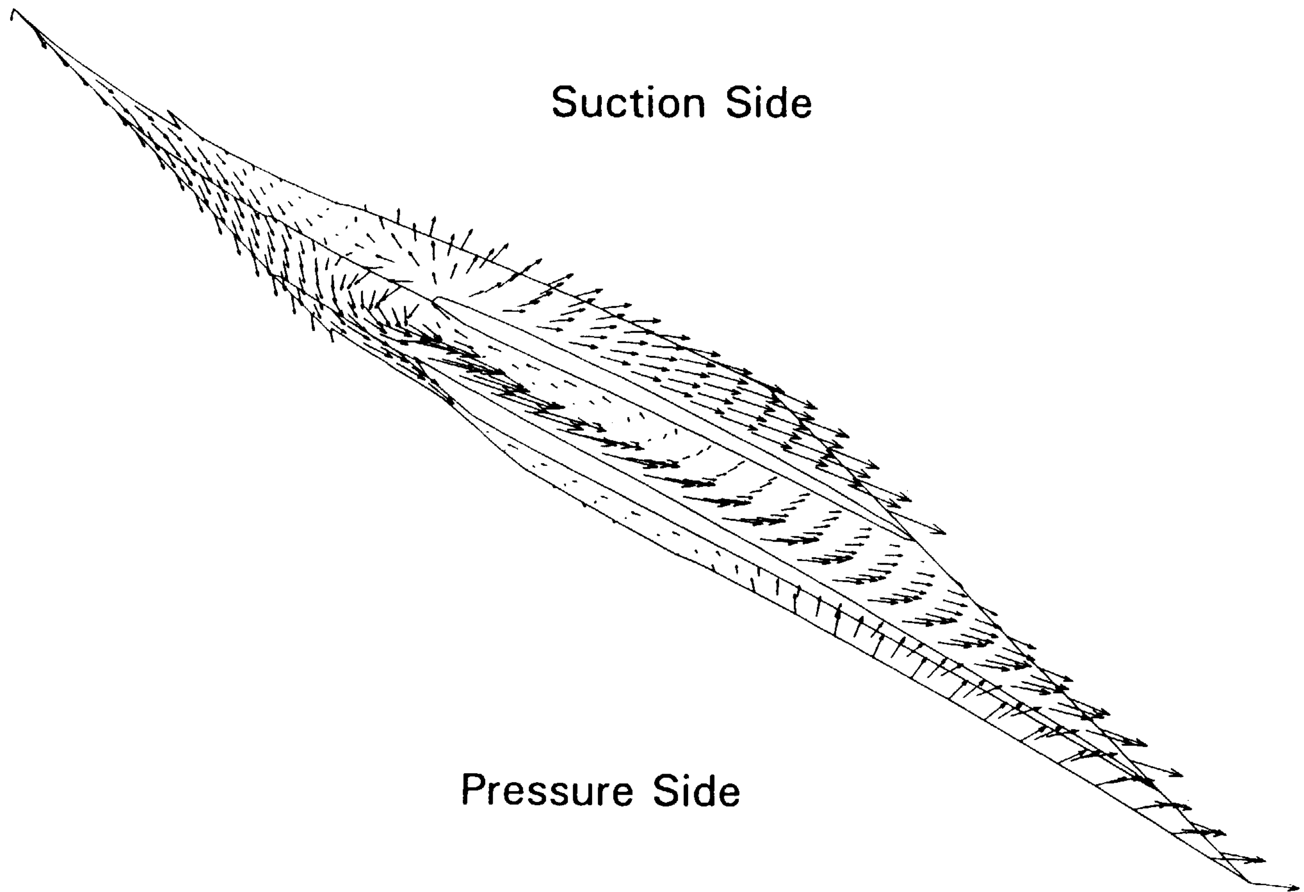
Velocity Vectors Near the Hub

7.5° TANDEM Blade



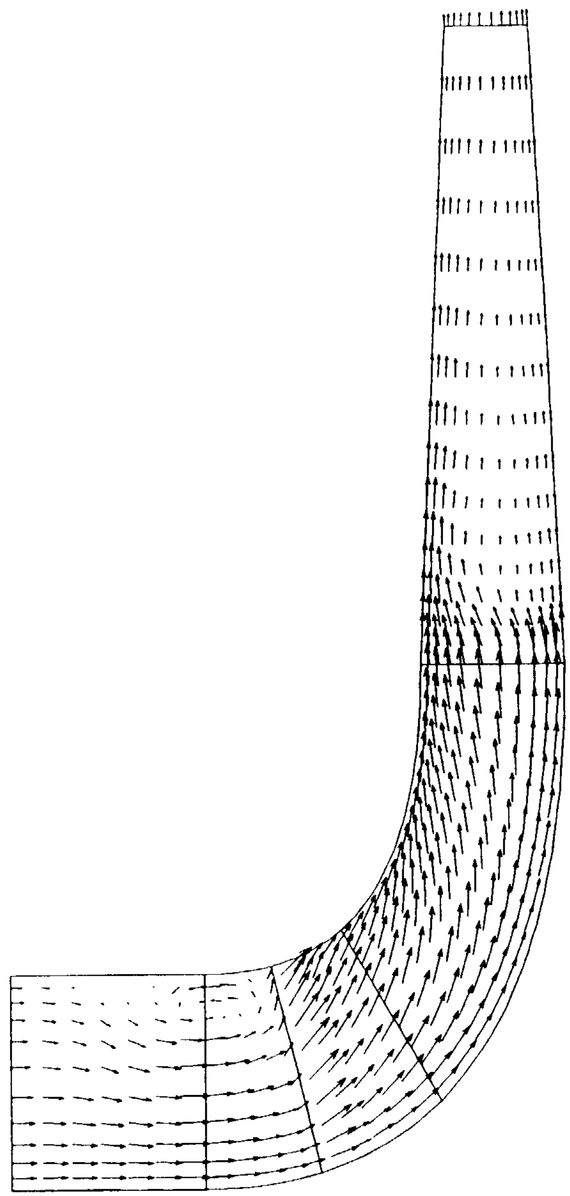
Velocity Vectors at the Mid Span

7.5° TANDEM Blade

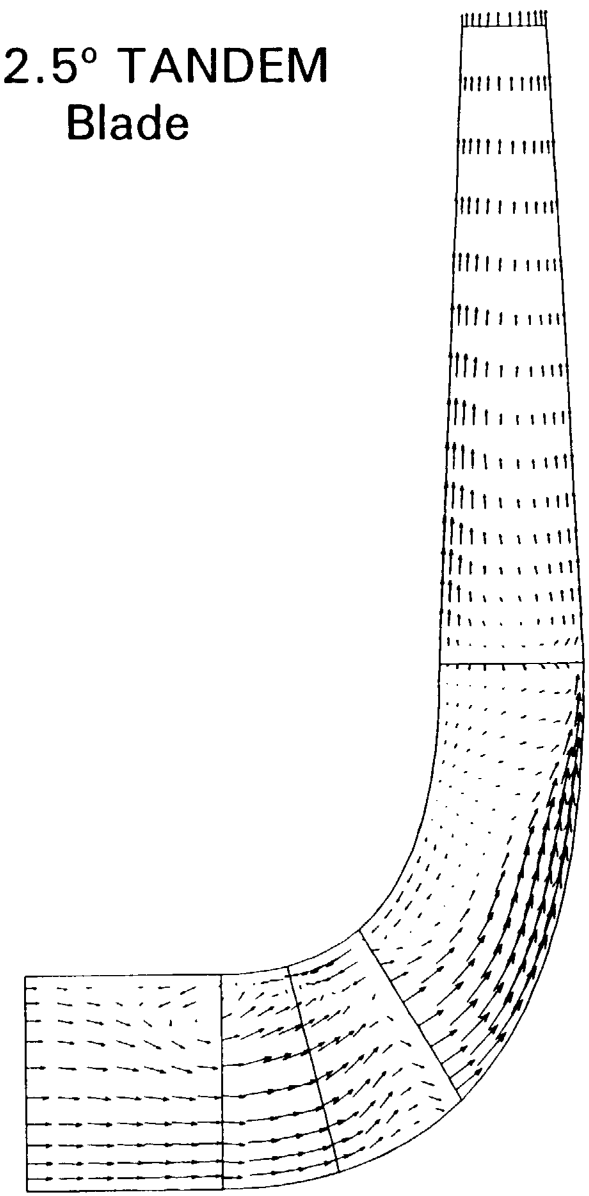


Velocity Vectors Near the Shroud

22.5° TANDEM
Blade

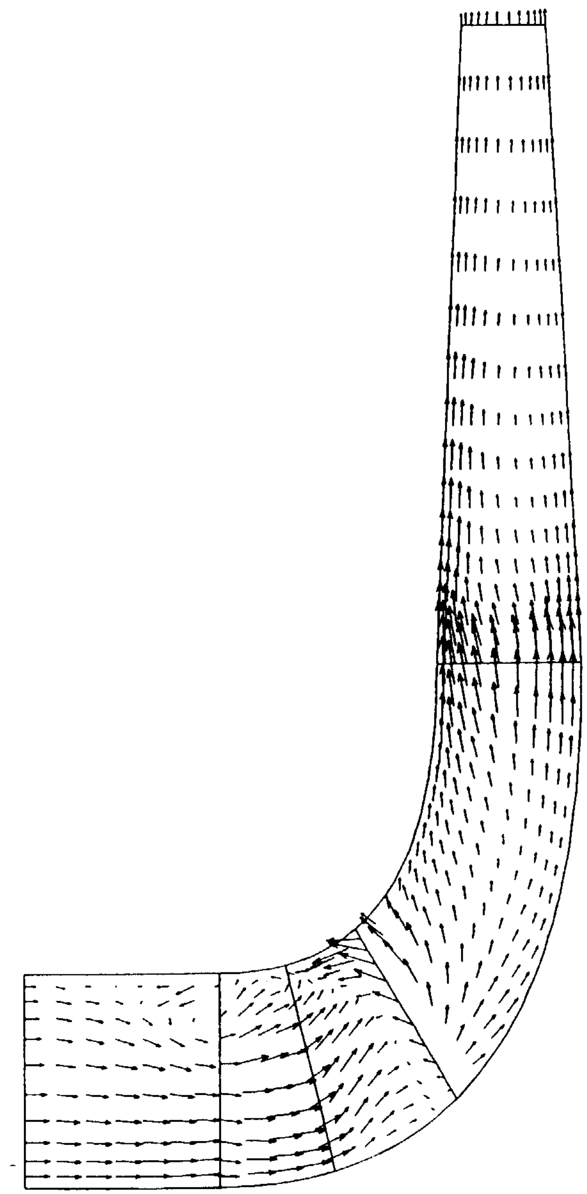


Pressure Side of Full Blade

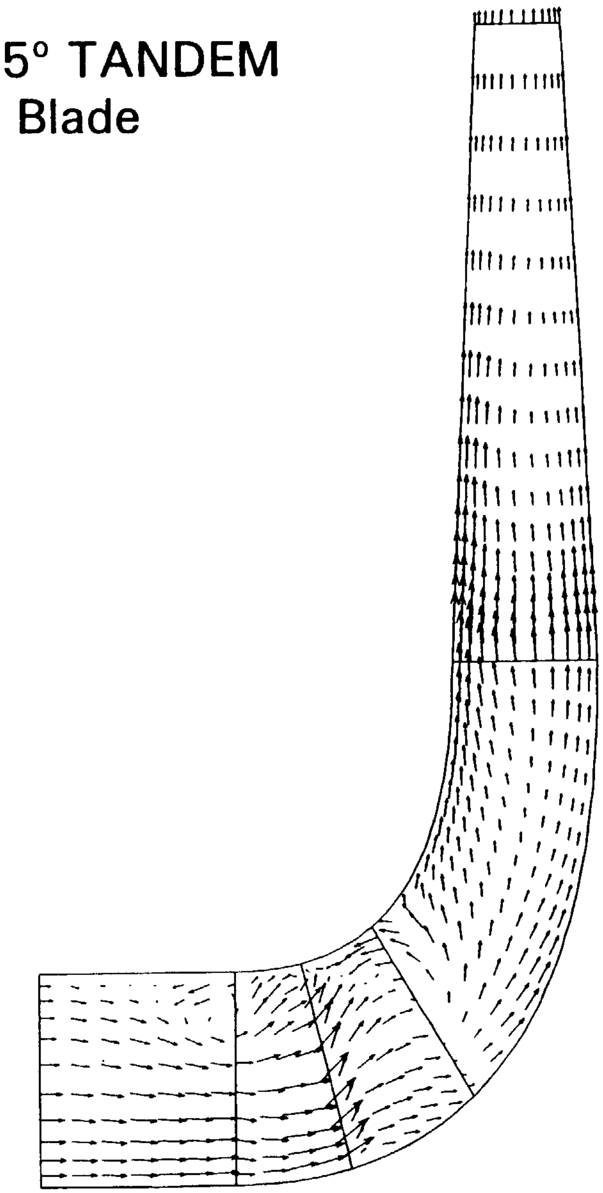


Suction Side of Partial Blade

22.5° TANDEM
Blade

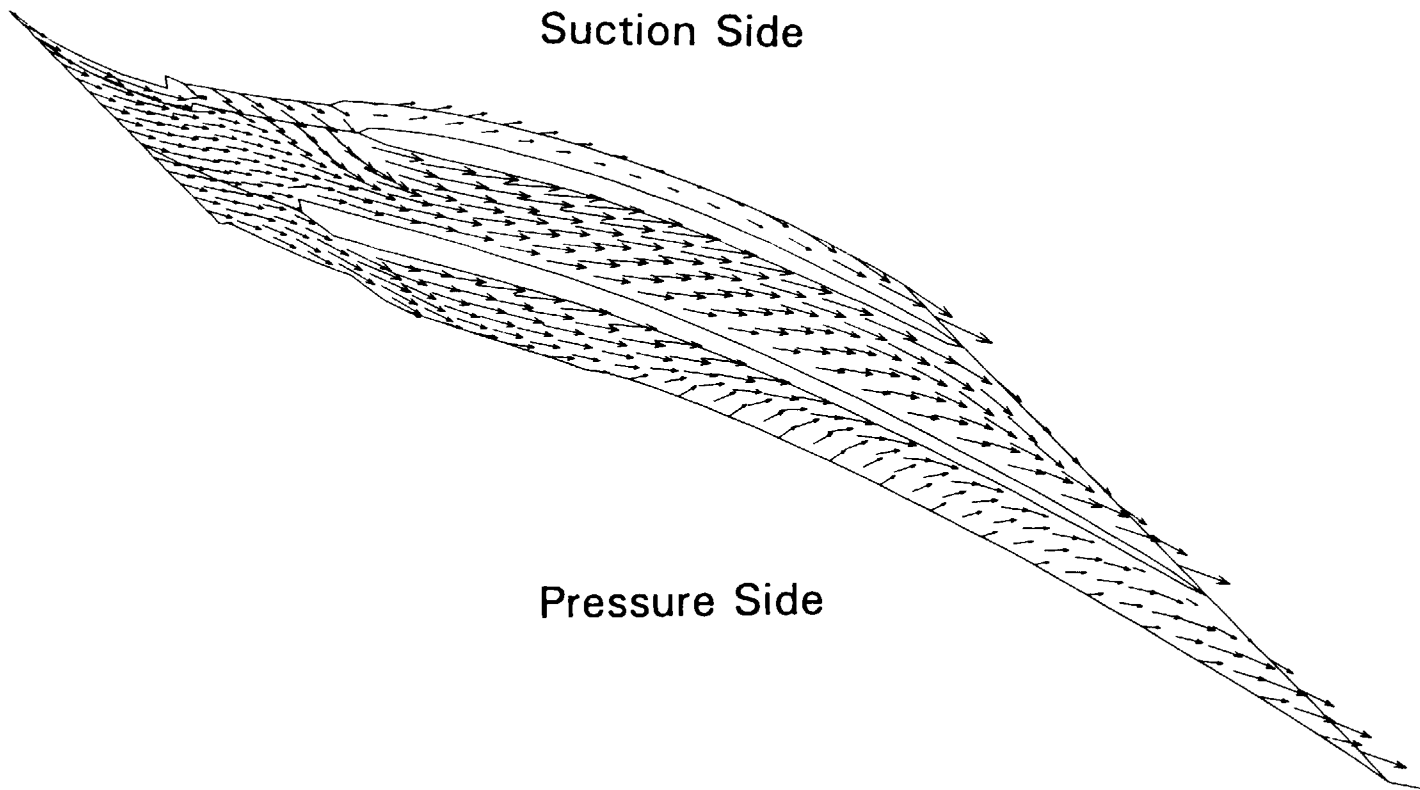


Pressure Side of Partial Blade



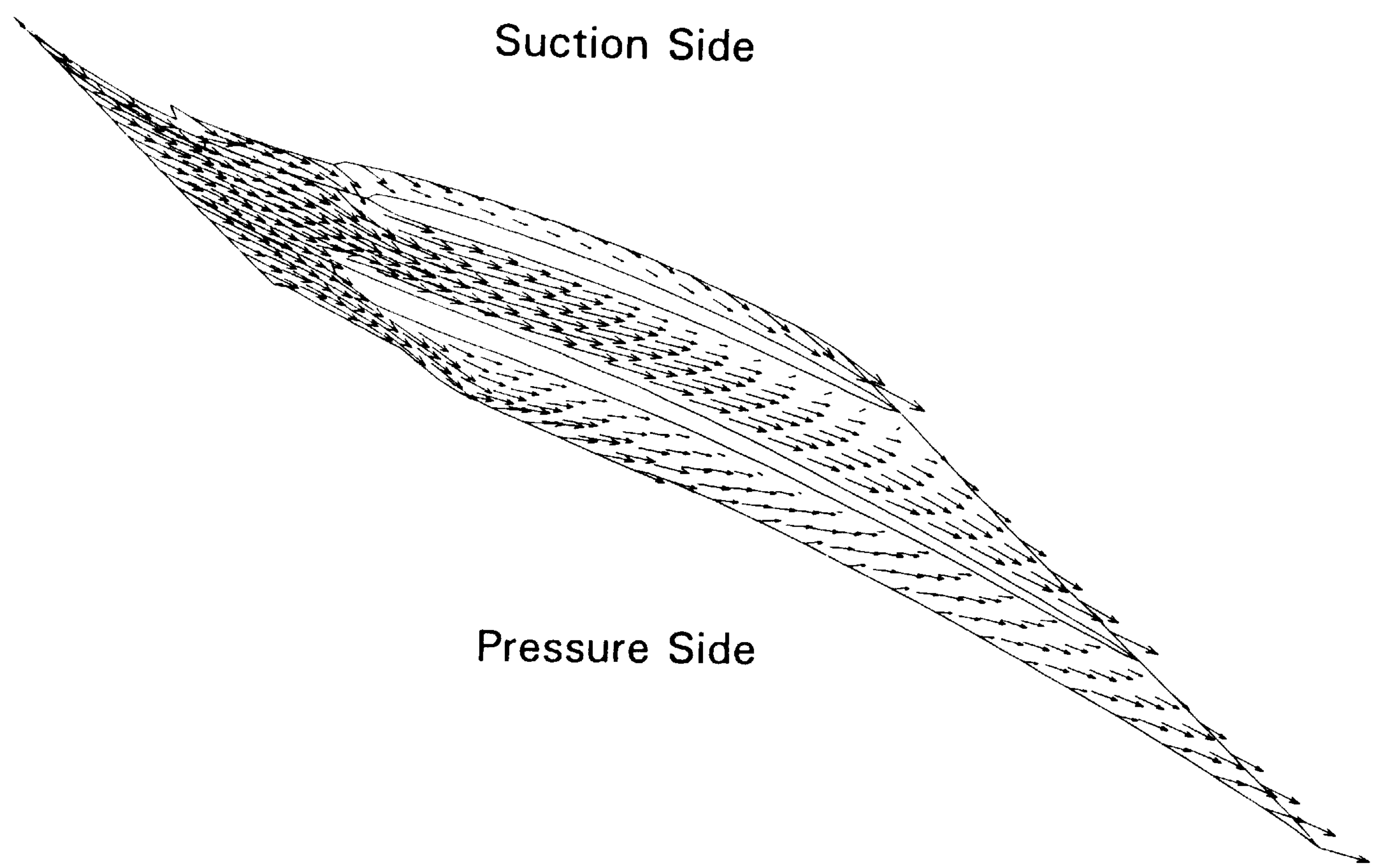
Suction Side of TANDEM Blade

22.5° TANDEM Blade

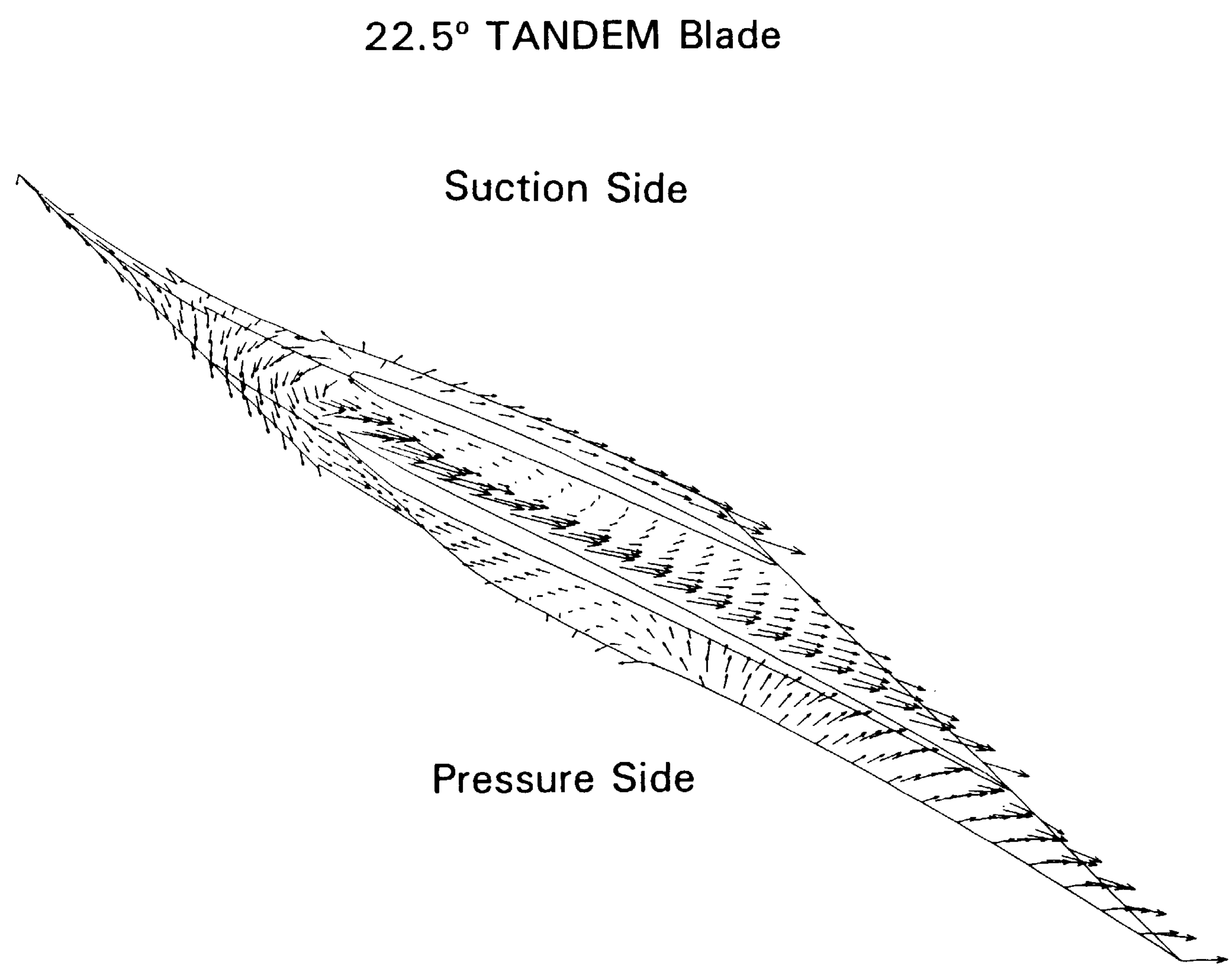


Velocity Vectors Near the Hub

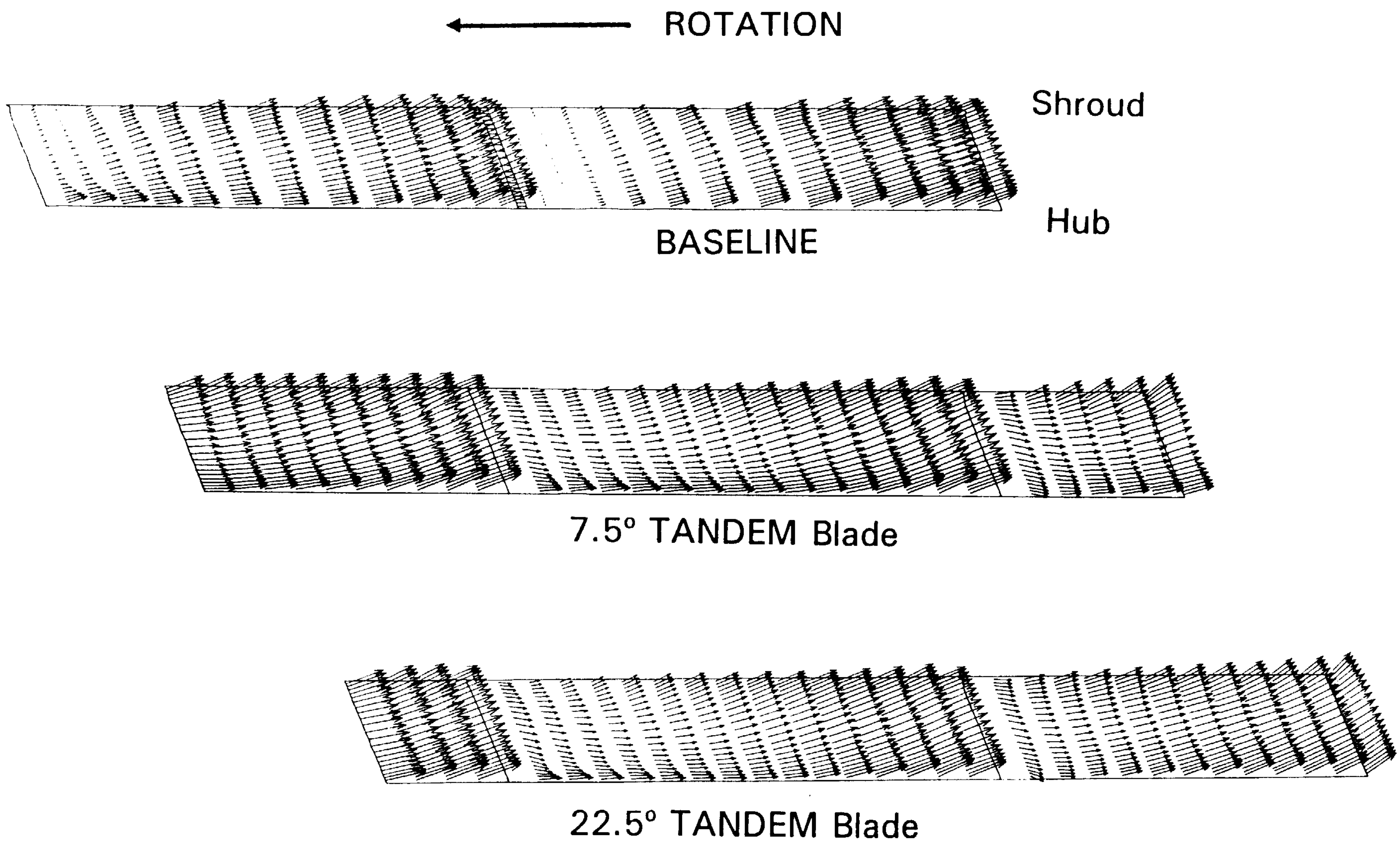
22.5° TANDEM Blade



Velocity Vectors at the Mid Span

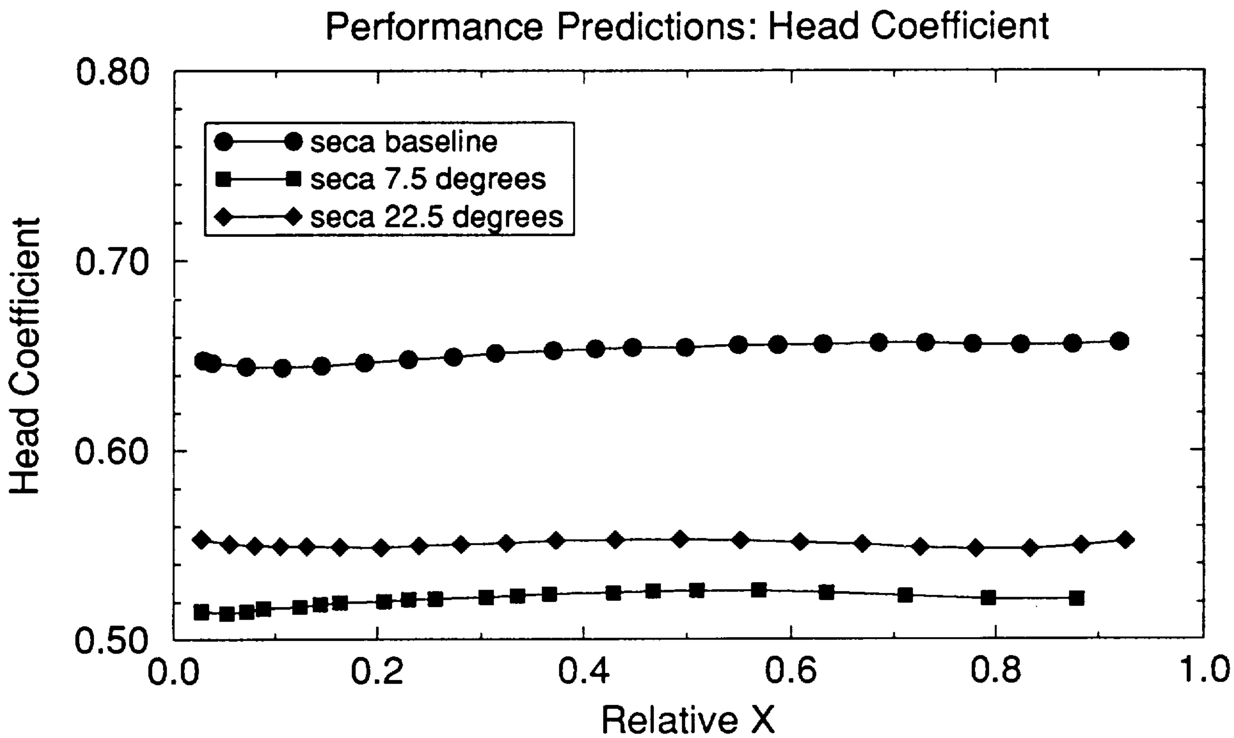


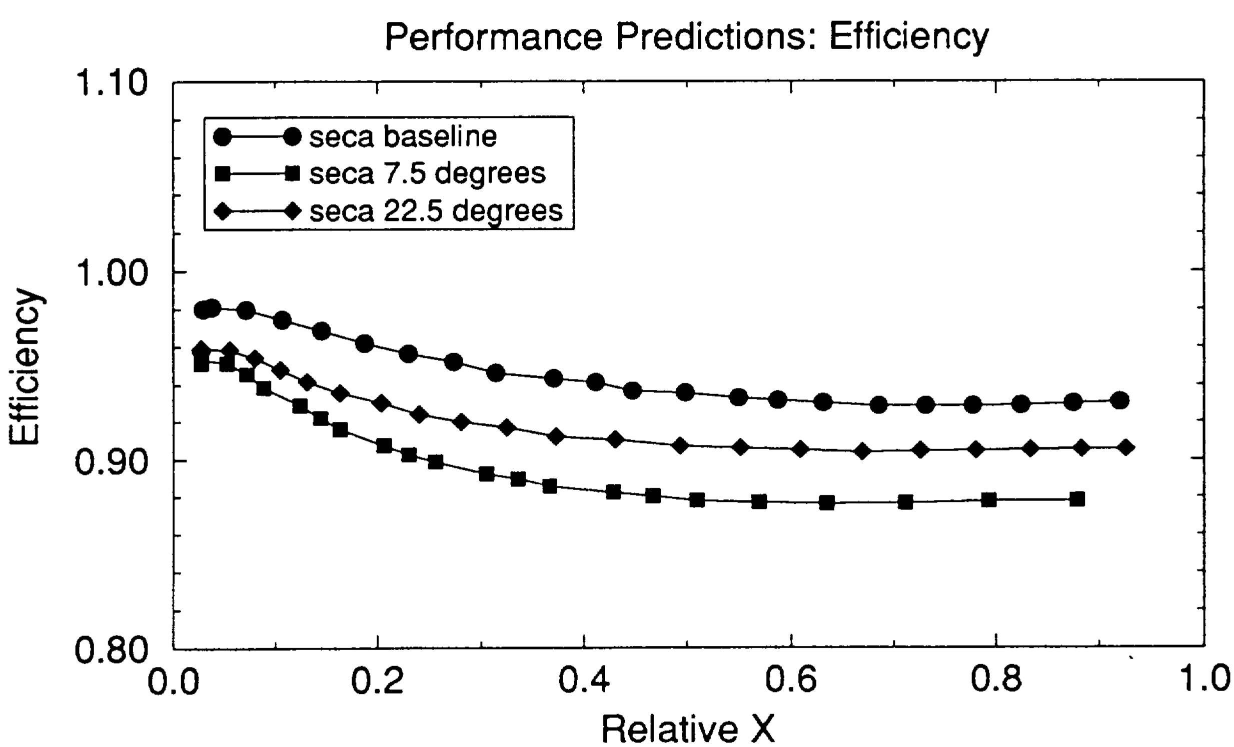
Velocity Vectors Near the Shroud



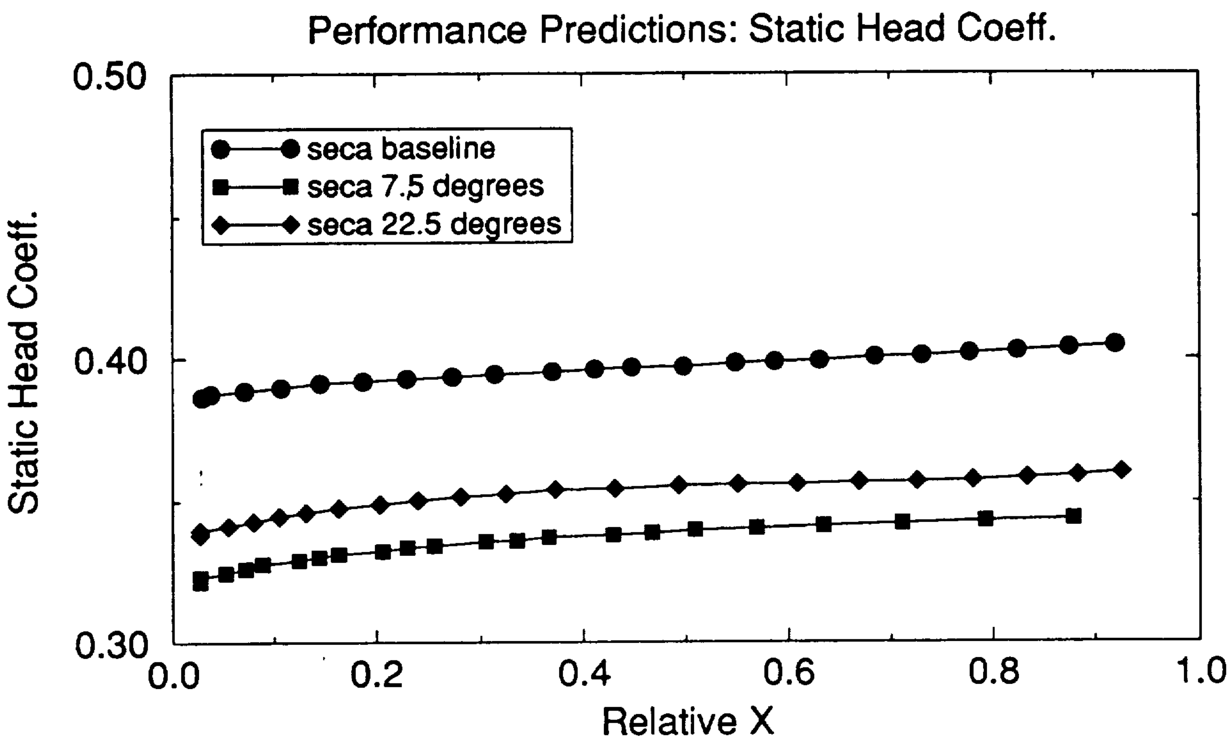
Velocity Vectors at the Exit of Impeller Blade

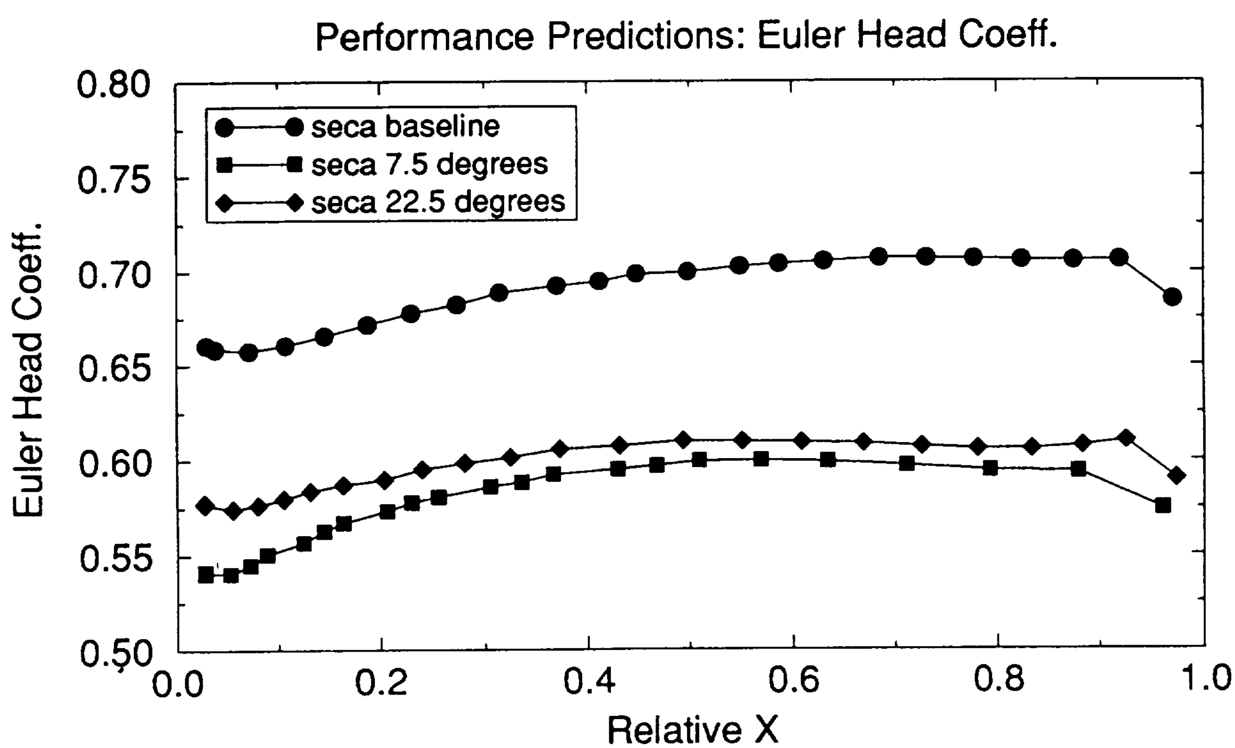
Advanced Impeller Parametrics: Tandem Blades

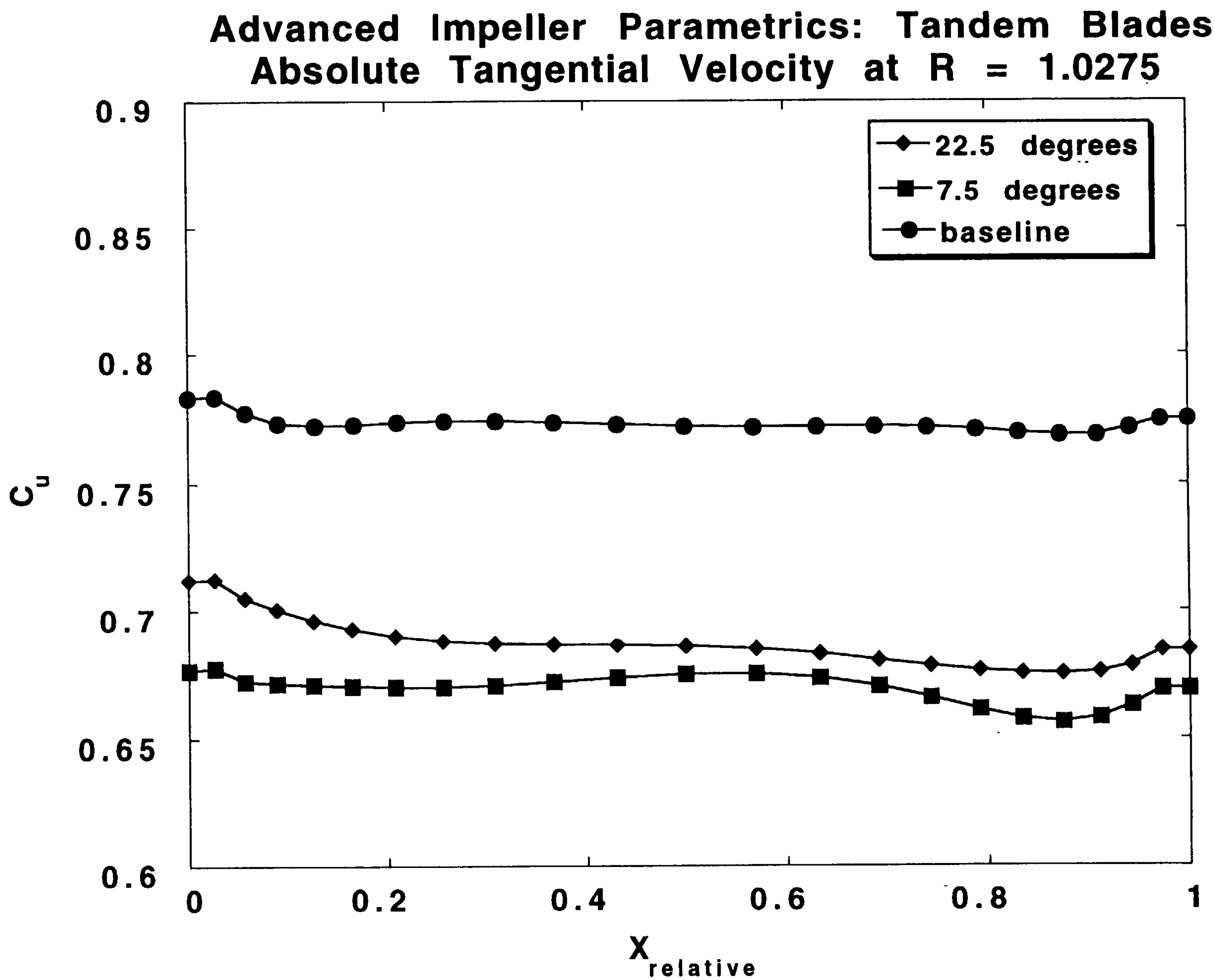


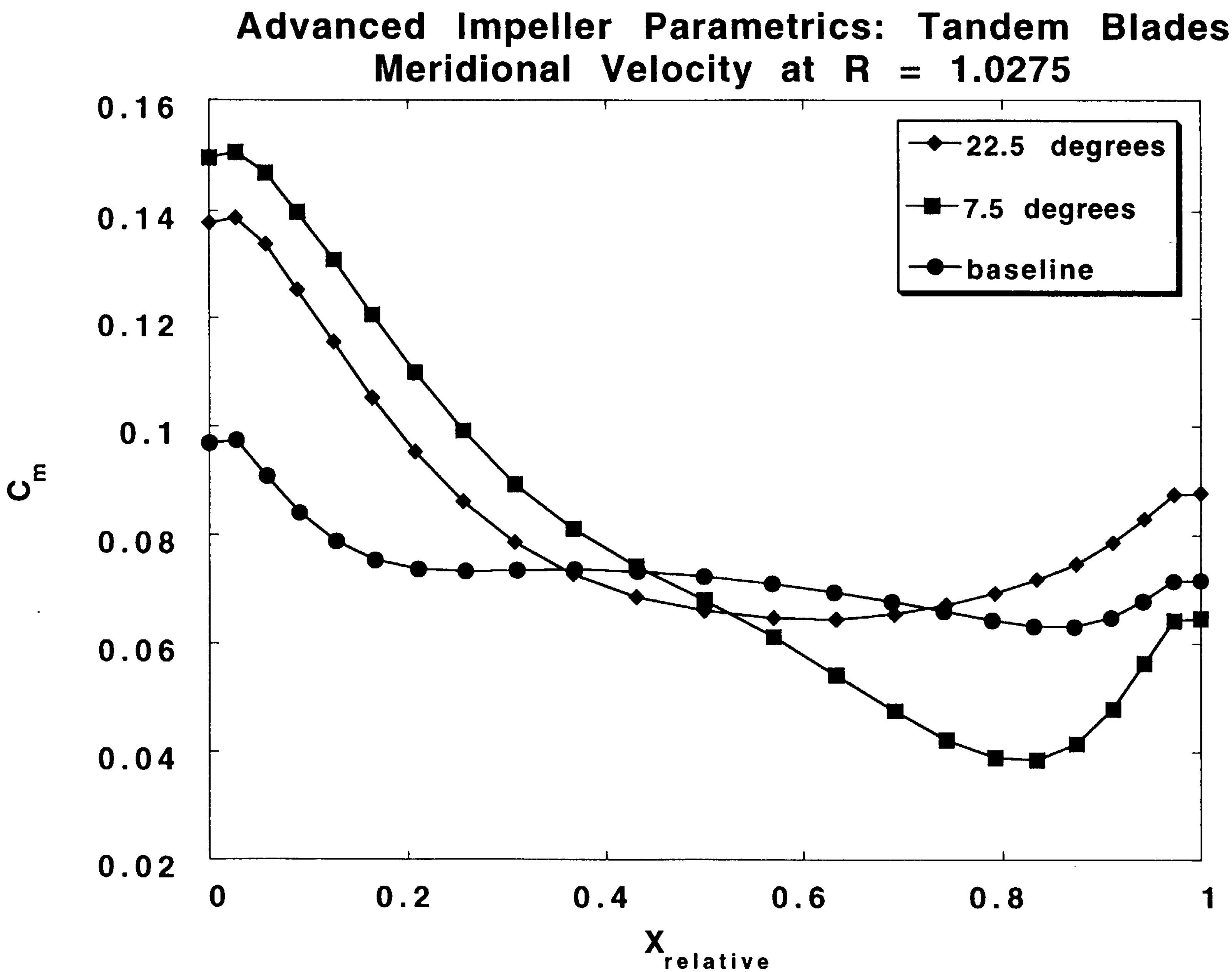


Advanced Impeller Parametrics: Tandem Blades






Advanced Impeller Parametrics: Tandem Blades
Absolute Tangential Velocity at R = 1.0275
22.5 degrees
7.5 degrees
baseline
C_u
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0
0.2
0.4
0.6
0.8
1
$X_{relative}$


Advanced Impeller Parametrics: Tandem Blades
Meridional Velocity at R = 1.0275
22.5 degrees
7.5 degrees
baseline
C_m
$X_{relative}$
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.2
0.4
0.6
0.8
1

SUMMARY

- THE MASS FLOW RATE SPLIT

BLADE ROW	S.F.B.-P.P.B. / S.P.B.-P.F.B.
BASELINE IMPELLER	48/52
7.5° TANDEM BLADE	56/44
22.5° TANDEM BLADE	60/40

- THE TANDEM BLADE MODIFICATION DID NOT IMPROVE THE IMPELLER PERFORMANCE